FEBRUARY, 1961

Welding Journal

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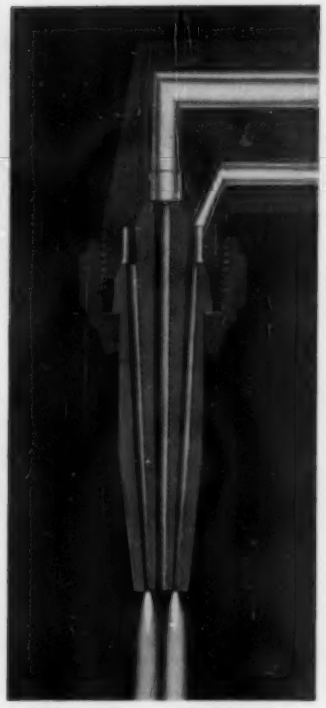

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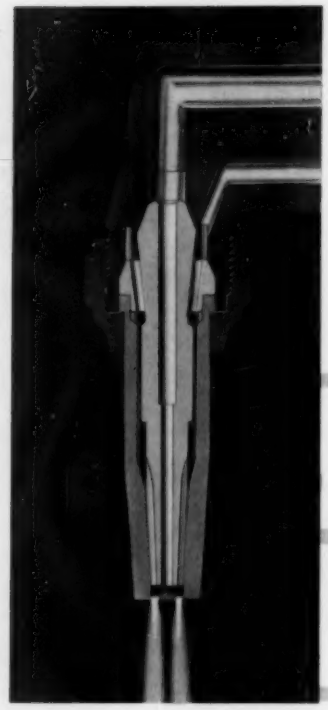

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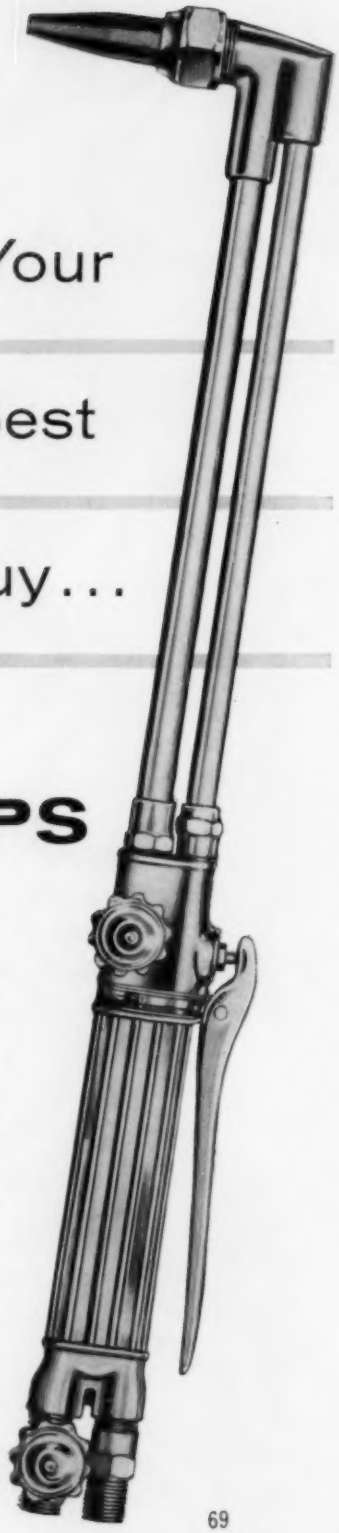

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Fisher Elected President of RWMA

Simon Fisher AWS, president of National Electric Welding Machines Co., Bay City, Mich., was elected president of the Resistance Welder Manufacturers' Assn. at their Annual Meeting in Detroit on December 16th.

Simon Fisher

The newly elected vice president for 1961 is Harry V. Beronius AWS, sales manager of Swift Ohio Corp., Kenton, Ohio.

Messrs. Fisher and Beronius have been very active in Association affairs for many years.

New Honors for Lincoln

James F. Lincoln AWS, chairman of the board of The Lincoln Electric Co., Cleveland, Ohio, was elected a senior board member of the National Industrial Conference Board for a term of three years at the Board's 409th meeting during mid-December, 1960, at the Waldorf-Astoria, New York, N. Y.

AWS Sustaining Members Prepare Answer to Government

Three welding industry leaders undertook to resolve a puzzling—and to them, unfounded—dilemma presented by the U. S. Dept. of Justice which recently accused all three of criminal contempt on previous price-fixing charges. The three are the Air Reduction Co., Liquid Carbonic Div. of General Dynamics Corp. and the Chemetron Corp. The Olin Mathieson Chemical Corp. was also cited but, like Chemetron, was not involved in the original action dating back to 1952.

According to the Dec. 23, 1960, *New York Herald Tribune*, the Air Reduction Co. knew of "absolutely nothing to justify the charges" while Olin Mathieson stated that it would "prove in court that there is no foundation to the complaint." A Justice Dept. official was said to have admitted that its action is "very, very rare."

Pittsburgh Salutes Minnotte

The Pittsburgh Section of AMERICAN WELDING SOCIETY recently announced that Joseph F. Minnotte was presented with a testimonial expressing thanks for his 30 years as secretary of the Section.

The testimonial acknowledged the unselfish and untiring efforts of Mr. Minnotte on behalf of the Section and expressed appreciation for his judgment and guidance. The testimonial was signed by all living past chairmen of the Pittsburgh Section, including two former presidents of the SOCIETY.

Mr. Minnotte has been active in the AMERICAN WELDING SOCIETY since 1919.

Sweepstakes Drawing for Airco Contest Winners

Thirty-eight grand prize winners of an Air Reduction Sales Co. nation-wide contest for its authorized distributor personnel were chosen recently by prominent New York editors in a sweepstakes drawing held at a luncheon in the Biltmore Hotel, New York City. The drawing culminated a ten-week contest designed to provoke study of Airco's new 112-page general products catalog by competing distributor personnel. Approximately 2100 employees of authorized Airco distributors enrolled in the contest; 1900 or about 90% completed all five quizzes.

Contest questionnaires were sent to the contestants at two-week intervals, beginning in September, and all contestants who completed and returned the entire series of quizzes received their choice of two Corning glassware pieces. Upon completion of all quizzes, a contestant became eligible for the sweepstakes drawing and one of the 38 grand prizes—RCA portable television sets, Westinghouse transistor clock-radios and Elgin wrist watches.

ONE OF THREE TV SET WINNERS

Tom O'Toole, Wall Street Journal staff writer, picks television set winner as Russ Schmidt, Air Reduction distributor marketing manager, looks on at sweepstakes drawing for Airco distributors

Sam Lenick (center) of Bay Welding Supply, Saginaw, Mich., admires television set which he won, with R. Jamieson (left) and Fred Syrne of Air Reduction looking on. Other TV set winners were J. McClure, Hoosier Welding Supplies, New Albany, Ind., and K. M. Williams, Kennerle Welding Supply Co., Miami, Fla.

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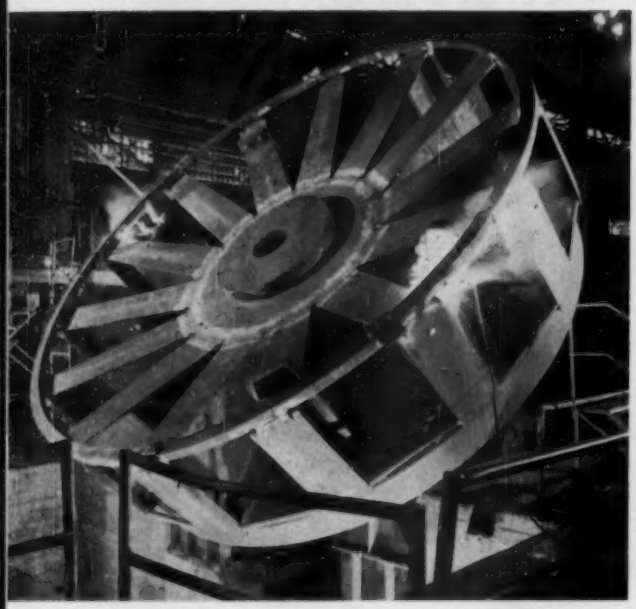
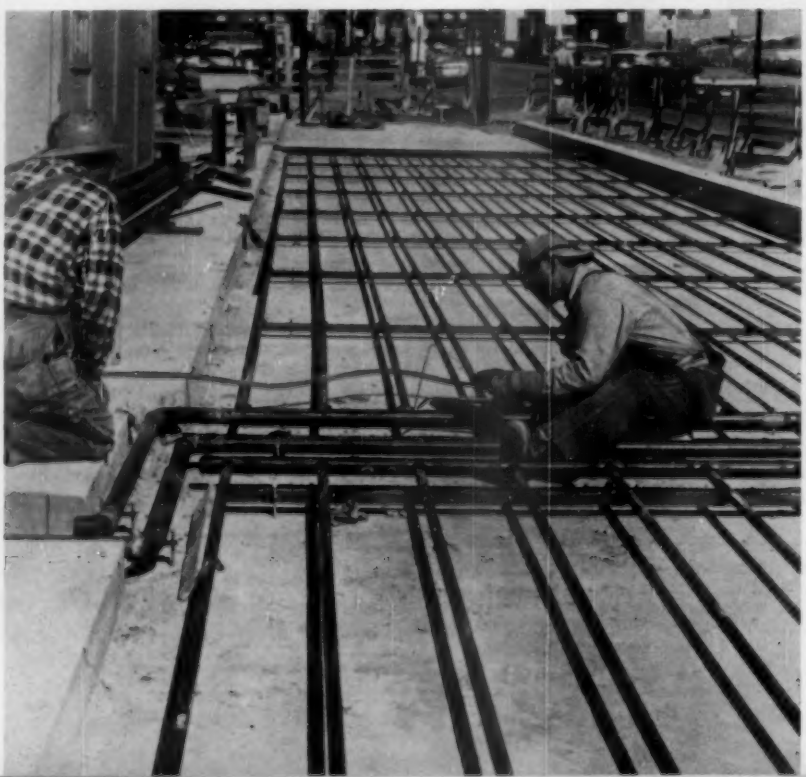
WELDING ZONES

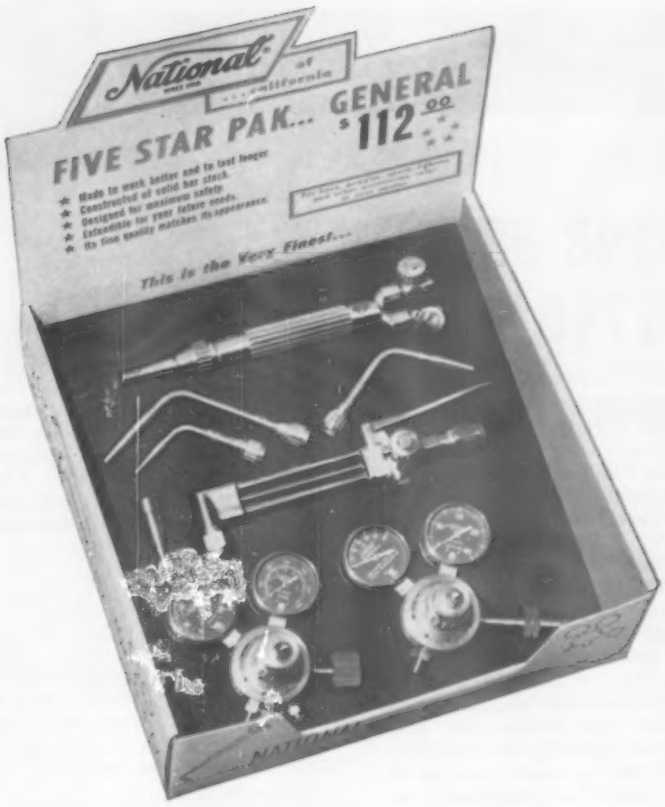


Giant spider for the Bull Shoals Dam located on the White River in Arkansas engulfs two welding operators. Representing the first of two generators that Allis-Chalmers Manufacturing Co. is supplying, this fabricated spider weighs 32 tons and is roughly 20 ft in diam.

Worn areas are built up on this cast steel blast furnace component before it is hard surfaced with $^1/_4$-in. thick metal applied to the 53-deg. tapered wall at the rate of about 33 ipm by submerged-arc welding. This money-saving technique is used by the Steel-weld Div. of R. C. Mahon Co. to fully restore and, at the same time, to increase the life of heavy (over 30 tons) parts.

Snow-melting system installed in sidewalk facing Ontario St. in Toledo, Ohio, was fabricated from Byers wrought iron pipe. Heat transfer oil that is circulated through the concrete-enclosed grid system will warm terrazzo topping, preventing any accumulation of ice and snow in the Libbey-Owens-Ford Glass Co. building area. (Courtesy A. M. Byers Co.)





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WORLD-WIDE WELDING NEWS

by Gerard E. Claussen

ARGENTINA

The second number of *Soldadura*, the magazine of the Argentina Welding Institute, appeared in March 1960. The first article on welding metallurgy was written by the Institute's president, Dr. V. Vilhalm. Other articles discuss silver brazing, and design of welded joints for buildings.

CZECHOSLOVAKIA

The Czechoslovakian welding magazine for March and April 1960 contains the following articles:

1. The application of tensile stress facilitates the intergranular penetration of brazing materials into steel and promotes cracking.
2. A machine for flash welding steel chain is described.
3. A Chinese researcher reviews the forces affecting metal transfer and bath circulation in electroslag welding. Pinch effect is the principal force invoked.
4. Automatic submerged-arc welding is used on site to double-lengthen pipe for the 250-mile Czech section of the 2500-mile pipe line linking Russia with the satellites. The pipe is 28 in. in diameter. Electrodes are $^{5}/_{32}$ or $^{1}/_{8}$ in. in diameter.
5. The economics of spot welder design and programming is discussed.
6. The so-called decarbonized zone in resistance butt or flash welded joints is shown to be a zone of divorced ferrite rather than true decarbonization.
7. Vacuum tight welds in Kovar and other vacuum tube metals are made on a production basis by resistance welding.

EAST GERMANY

The East German magazine *Schweisstechnik* for April 1960 contains the following articles.

1. CO_2 welding is widely used for machinery construction, surfacing wheels, sheet-metal welding (0.032-in. wire for 0.039-in. sheet, 100 amp) and steel-casting repair. Objections to CO_2 have been the complexity and weight of the controls and torch. A new East German wire feeder for semi- and full-automatic welding weighs only 11 lb. A torch without water cooling operates at 300 amp. A torch cooled with compressed air is in use.
2. Automatic and semiautomatic equipment for three-phase submerged arc welding is described. For steel casting repair three phase welding with $^{5}/_{16}$-in. electrodes deposits 4.2 lb/hr/100 amp. Energy consumption is 1.0 kw hr per lb compared with 1.5 kw hr per lb for single phase welding.
3. A mechanical device has been developed for automatically moving an ultrasonic testing crystal along a weld in the vertical or flat position. The crystal is moved along the seam at a speed of 8 ipm.
4. A long review of literature on the welding of atomic reactors emphasizes the importance of weld testing.
5. Fatigue tests showed that in the field welding of plate girders welding sequence was important. If the web was welded first then the upper and lower flanges the fatigue strength at 500,000 cycles was 21,-300 psi. When the upper and lower flanges were welded before the web the fatigue strength was 32,000 psi.
6. The third Rumanian welding conference was held in Timisoara in December 1959. During the 4-day meeting 51 technical papers were read. One paper described biaxial fatigue tests on welded tubes. Another described covered electrodes with mild steel cores to deposit cast iron containing 3.5% carbon. A third applied the energy of an electrostatic field to weld automotive spark plug electrodes. A visit was paid by the conferees to the Resita Steel plant consisting of blast furnaces, rolling mills, coke plant and shops for turbo-generators and locomotives. About 350 production welders were employed of a total payroll of 20,000. Domestic electrodes made at the Sirmei plant were used almost exclusively.

ITALY

The Italian Welding Society magazine for March-April 1960 contained an account of the welding of the boilers for the Latina nuclear power plant. The steel was A201 Grade B, 0.16% C max, 2 in. thick. Block sequence was used for the manual butt welds. The submerged-arc butt welds required 34 passes, split weave. Another article in the same issue compared four submerged-arc fluxes. The ratio of flux to wire varied from 0.46 to 1.12 for the different fluxes.

THE NETHERLANDS

The Netherlands welding magazine for April 1960 contains a description of the welding of field storage tanks and pipe lines at the Shell refinery in Europoort near Rotterdam. A cored automatic electrode was used for the horizontal seams of the tanks. American practice with 6010 and 7010 electrodes was adopted for the pipe lines.

SWITZERLAND

The Swiss welding magazine *Journal de la Soudure* for May 1960 contains the 1959 Annual Report of the Swiss Welding Society, formerly Swiss Acetylene Society. Business in general was good in 1959. Power supplies and inert-gas-shielded welding equipment were sold in larger volume than in 1958, and foreign interest was increasing. Argon consumption increased a little, but CO_2 production remains insignificant. Imports of foreign

DR. GERARD E. CLAUSSEN is associated with Arcrods Corp., Sparrows Point, Md.

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covered electrodes lowered prices a little. Resistance welder sales were good, especially for machines developed for radiators. Hard polyethylene and other plastics were applied to an increasing extent for plumbing, welding being used for joints. During 1959 the Society gave 85 theoretical-practical welding courses to 1006 students.

USSR

The February 1960 issue of *Avtomaticheskaya Svarka* contains the following articles:

1. An appreciation of the work of E. O. Paton on his 90th birthday.

2. A comprehensive discussion is given of literature and new information is developed on heat-affected-zone cracking in hardenable steels. Submerged-arc welds were made in 0.55-in. steel containing 0.35 C, 3 Cr, 3 Ni, 0.25 Mo at 600 amp, 12 ipm with $^1/_8$-in. electrodes of plain-carbon, low-alloy and austenitic steels. Cracks in the heat-affected zone appeared a few minutes or hours after welding and grew slowly. Bend tests nevertheless showed a gradual increase in ductility with time. Shrinkage stresses were lowest with the low-alloy steel electrode. Microstructural investigations showed that cracks formed as a result of three-dimensional shrinkage stresses acting on martensite needles. Cracks start at grain boundaries, but eventually progress across the grains. Four means for preventing cracking are recommended: (*a*) Suitable alloy-steel weld metal should be used to prevent gamma-alpha transformation in the 200–400° F range; (*b*) Cooling should be slow in this range; (*c*) Ultrasonic vibrations should be applied to the weld after its completion; (*d*) Limit the hydrogen content of the steel and weld metal.

3. Linear and angular distortion were measured in two electroslag welded assemblies—a machine base and a ring. Distortions were small and were compensated by applying heating torches to the zones adjacent to the weld.

4. A vacuum diffusion welding unit is described. It consists of an evacuated chamber in which the parts are heated to accomplish a diffusion weld. The welding cycle requires 6 to 18 min at 10^{-3} to 10^{-4} mm mercury.

5. A study of microstructure and hardness of titanium alloys welded by argon-shielded and submerged-arc processes showed that alloys containing beta-stabilizing elements showed less tendency to grain growth in the heat-affected zone than the alpha and alpha-plus-beta alloys. Cracking in the heat-affected zone was more prevalent in alloys containing elements (Fe, Cr, Mn) that formed hard intermetallic compounds with Ti, than with elements (Mo, V, Cb) that did not.

6. Creep tests were made on weld metals containing 1 Cr, $^1/_2$ Mo, 0.10 C with and without 0.24 V. The weld metals had better creep resistance at 1020° F than base metal of similar composition. Substructures formed in the ferrite of the weld metal as a result of strain during cooling. The substructure raised the creep strength and suppressed irregular creep.

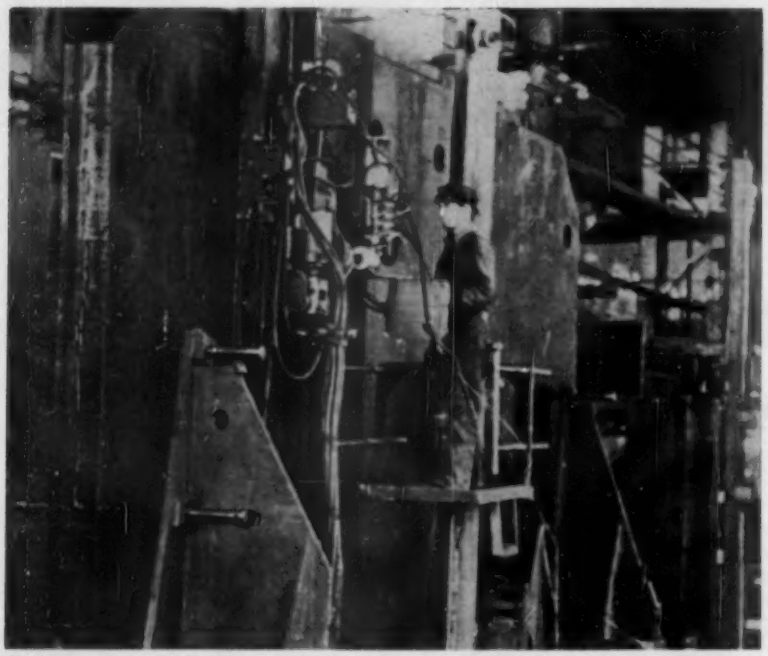
7. Condenser discharge welds were made in mild steel sheets with projections formed by a ball bearing 0.10 in. diam. The weld nuggets were sound and strengths were high.

8. The coating formula is given for low-hydrogen electrodes to repair cast steel. The welds contained 1.7 Ni with or without 0.7 Cr.

9. The butt welding of rock drilling pipe containing 0.60 C by the submerged-arc process with mild-steel electrode and standard high-manganese flux is described. The welds were made in several continuous layers, no preheat being required.

10. Electroslag-heated risers for ingots of steel containing 0.55 C, 1.2 Ni, 0.75 Cr decreased the quantity of nonmetallic inclusions, and distributed them more uniformly than without heating.

SOVIET UNION



Electroslag welding of heavy-duty hydraulic press plate in a Soviet factory. The 68.63-ton plate is approximately 16 × 8 × 0.56 ft.

WEST GERMANY

The surfacing of blooming and slabbing mill rolls by the submerged-arc process is described in the Apr. 14, 1960, issue of *Stahl und Eisen* (West Germany). The procedure for a 34 ton roll 50 in. diam surfaced over a length of 9 ft consists of depositing a buffer layer $^3/_8$ to $^5/_8$ in. thick followed by a wear-resistant layer 3 in. thick. The roll contained 0.57 C, 0.72 Mn, 0.36 Si, 0.20 Cr and was heated 8 hr at 1200° F. It was cooled to 600° F at which welding was performed without interruption. Upon completion of welding the roll was heated 10 hr at 1000° F. The buffer layer was deposited with a wire containing 0.16 C, 2.00 Mn, 0.18 Si, 0.52 Mo, 0.08 V, 0.30 Cr. The wire for the wear-resistant layer contained 0.09 C, 0.59 Mn, 0.26 Si, 6.13 Cr, 0.65 Mo, 0.08 V. For some rolls a two-wire head was used with $^3/_{16}$-in. wires 1300 amp, a travel speed of 30 ipm and a deposition rate of 32 lb/hr. The surfaced roll had a longer service life than the original roll.

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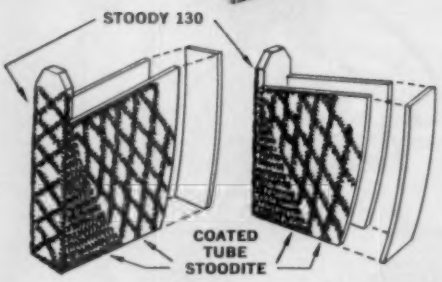

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IIW Prestige Abroad

Those who have the opportunity of meeting and talking with our distinguished overseas gentleman and lady guests will have a rare opportunity indeed. Participants in the International Institute of Welding's Assembly in the United States—the first Assembly ever held outside Europe—are community leaders in every sense of the word. Not only are these representatives from 27 countries world leaders in welding and related arts, but they have achieved eminence in industry, in welding and related arts, but they have achieved eminence in industry, in science, in education and in manifold relationships to their own peoples.

That this exceptional personal and professional standing—perhaps little known here—is universally acknowledged abroad, has been shown in that all previous assemblies have been held under sponsorship of government leaders of host countries. For example, last year at Liège, the President of Honor was His Royal Highness, Prince Albert of Belgium. The committee of Honor comprised, among others, Ministers of Cultural Affairs, of Public Works, of Education, of Economic Affairs, not to mention Rectors of Universities and Directors of National Scientific Bodies.

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Atomic power for historic New England will flow from Yankee Atomic Electric's plant at Rowe, Mass.

Materials and shop welding techniques are described for the

Primary **Piping System** of the Yankee Atomic Electric Plant

BY R. R. ROTHERMEL AND R. A. LOOSE

ABSTRACT. The size, wall thickness and use of stainless steel material for the primary piping system of the Yankee Atomic Electric Plant dictated unique fabrication techniques. Although the fabrication techniques for nuclear piping systems will soon be considered conventional, quality control standards must be maintained at a high level. The material, fabrication techniques and control requirements for the primary piping system of the Yankee pressurized water nuclear power plant located at Rowe, Mass., are described in this paper.

Introduction

Construction of New England's first atomic energy plant is practically completed. On November 10, 1960 power generated from the atom started to flow from Yankee Atomic Electric Company's 134,000 net electrical kilowatt pressurized water nuclear power plant. The eleven major New England utilities which formed Yankee Atomic Electric Co. supply approximately 85% of the electrical requirements of the six-state New England region.

The Atomic Power Department of the Westinghouse Electric Corp. was selected to develop, design and furnish the nuclear steam generator portion of the power plant. The Stone & Webster Engineering Corp. was designated as the architectural engineer-constructor for the balance of the plant. The stainless steel primary piping system was shop-fabricated by the National Valve and Manufacturing Co.

Since leakage of primary coolant is to be avoided in a pressurized water nuclear power plant, a piping system containing the coolant must have sufficient integrity to prevent the possibility of such an event from occurring. Although it is common practice to bend pipe with wall thicknesses and sizes comparable to the Yankee primary piping system, the stainless steel pipe material specified for the Yankee plant made the bending operation quite unusual. The basis for the design and the fabrication techniques which were employed are presented in the following discussion and illustrate how the unique requirements of a large primary piping system in a pressurized water nuclear plant were met.

Primary System Layout and Design

The primary system consists of four closed loops

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Paper presented at AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

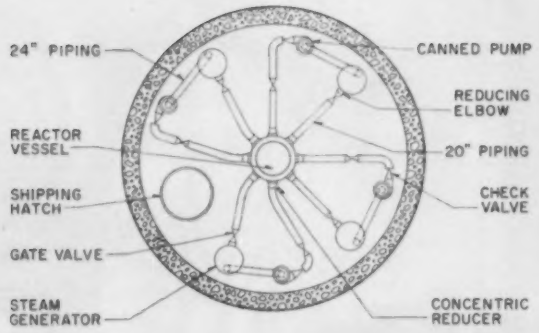

Fig. 1—Primary system layout showing reactor components

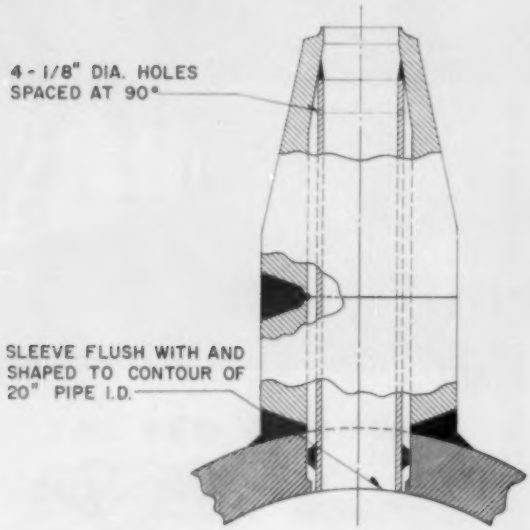

Fig. 2—Thermal sleeve design

Fig. 3—Completion of 33 deg hot bend in 20 in. OD by 2-in. wall, stainless Type 304 pipe conforming to ASTM A376 specification

Fig. 4—View of bend in stainless steel pipe showing weld joining stainless with carbon steel shoeing leg

contained in a spherical vapor container—Fig. 1. The major items of equipment in the primary system include the reactor vessel, four vertical "U" tube steam generators, four canned motor circulating pumps, a pressurizer vessel, eight loop isolation valves and four check valves. The primary system components are connected with 20- and 24-in. diam pipe. Pipe size was chosen on the basis of pump hydraulic characteristics and optimum economic-pressure drop considerations.

The design of the plant provides for a hatch opening in the lower half of the vapor container. By means of this opening, the primary plant polar crane can transport the large nuclear components directly from a railroad car into their permanent locations. Field handling of the large components installed in the vapor container was greatly simplified by this special hatch design feature; however, it was not considered feasible to obtain symmetrical loops, and four pipe bends were required because of the hatch opening.

In those branch connections where the incoming fluid is at a considerably lower temperature than the main coolant, depending upon the thermal cycles anticipated, thermal sleeves are employed. The design of the thermal sleeves is such that 100% weld penetration is obtained at the root joint, but the flow area through the connection is not reduced—Fig. 2. In order to prevent collection of corrosion products in the connections, the thermal sleeves are installed on the upper half of the primary piping.

The design and materials of the primary coolant piping system are in accordance with the requirements of the ASA B31.1 Code for Pressure Piping, and the fabrication of the piping system is in accordance with P-112 of Section I of the ASME Boiler and Pressure Vessel Code.

The operating pressure and temperature of the primary system is 2000 psi and 514° F, respectively

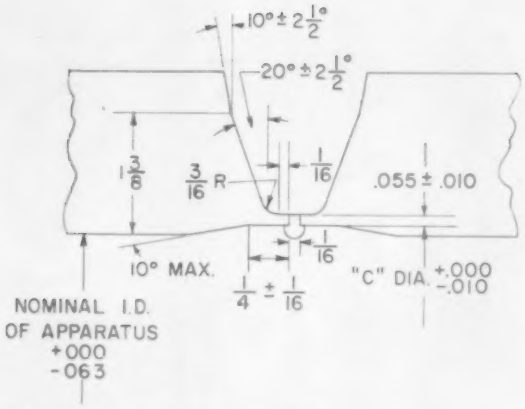

Fig. 5—Joint design for shop and field welds of main coolant piping

Using design conditions of 2300 psi and 550° F, minimum wall thicknesses of 1 7/8 in. for the 20-in. diam pipe and 2 1/8 in. for the 24-in. diam pipe were selected. Since the pipe material is austenitic stainless steel and the water quality is rigidly controlled, corrosion is negligible. Consequently, no specific corrosion allowance was included in the pipe wall calculations.

Material

One of the many unique requirements of a pressurized water nuclear power plant is that corrosion products in the primary coolant water must be maintained at a minimum level. Therefore, austenitic stainless steel was selected for the pipe and fitting material because of its superior corrosion resistant properties. Type 304, hollow-forged and bored pipe and Grade CF-8, cast stainless steel fittings were chosen for the primary piping system.

The hollow-forged and bored pipe used for the primary piping system met the requirements of ASTM Specification A-376. As a supplementary requirement to ASTM A-376, the pipe was 100% ultrasonically inspected. Although an internal finish of only 250 micro-in. rms was specified, the internal finish of this pipe as received from the manufacturer was approximately 70 micro-in. rms. A total of 185 ft of pipe was required for the primary piping system. The lengths of pipe range between 1 1/2 and 17 ft, each length of pipe being hydrostatically tested to 3750 psi by the pipe manufacturer.

The Grade CF-8 stainless steel fittings were cast and inspected in accordance with the requirements of ASTM Specification A-351. The uniform wall fittings consisting of reducing elbows, 90 and 30-deg elbows, and concentric reducers were 100% radiographed and dye-penetrant inspected. Radiographic acceptance standards were ASTM E-71, Class 2. Linear discontinuities revealed by the dye penetrant inspection, or by visual inspection, were removed and repair welded.

Bending

As previously mentioned, the design of the loops made it necessary to fabricate four sections of the main coolant piping by hot bending. The lengths of the pipe sections involved varied from 13 to 17 ft. The angles of the bends were two of 18 deg, one of 31 deg and one of 33 deg, while the bend radius was five pipe diameters. The pipe was 20 in. OD with a 2-in. thick wall which included 3/16 in. allowance for wall thinning on the outer arc of the bend. As the tangent point on one end of the bend was 4 in. from the end of the pipe, it was necessary first to weld a length of pipe to the stainless to provide leverage for shoeing during the bending operation. Using a stainless Type 310 electrode, one end of a piece of carbon steel pipe of the same OD and wall thickness was beveled and "buttered." A weld bevel was machined on this end, and both carbon and stainless steel pipe were butted together. They were then welded automatically by the submerged-arc process with a stainless Type 308 electrode.

Prior to heating the pipe in the furnace, the interior and exterior surfaces of the stainless were cleaned to remove all traces of oil, grease or carbonaceous materials. Chromel-Alumel thermocouples were located on the interior surface of the stainless pipe midway along the length of the arc and at a similar point on the exterior surface. After being filled with a high silica sand low in iron oxide content, the pipe was placed in a conventional natural gas-fired pipe furnace. The pipe was positioned to avoid direct flame impingement on its surface, and the bend arc only was heated to 2100° F as determined by the thermocouple attached to the interior surface. The heated section was allowed to soak for 1/2 hr at this temperature to ensure uniformity of temperature throughout the wall thickness. Figure 3 shows one of the stainless pipe sections at the completion of the bending operation. A pipe template, preformed to the desired bend angle, indicates completion of the bend. Layers of sheet asbestos have been placed around the heated section to maintain uniform temperature distribution during bending and subsequent cooling.

Figure 4 is a closer view of the bend area and shows the weld joining the stainless pipe with the carbon steel pipe. The small diameter pipe through which the thermocouples were inserted and held in place against the pipe surfaces is also shown.

After the bend section had cooled to room temperature, the thermocouples were removed, the sand drained from the pipe and the surface of the bend cleaned. Ultrasonic testing was then performed to determine the extent of wall thinning and investigate the soundness of the bend area. After all four sections had been bent, they were solution-annealed at 1925° F. The sections were held at this temperature for 2 hr and water-quenched. Inspection of the sections showed no distortion due to this operation. All surfaces were grit-blasted with iron-free aluminum oxide. Ultrasonic testing indicated that

Fig. 6—Manual metal-arc welding joining stainless Type 304 pipe and fitting—argon gas back-up maintained while welding—window used to observe progress during fusion welding of consumable insert

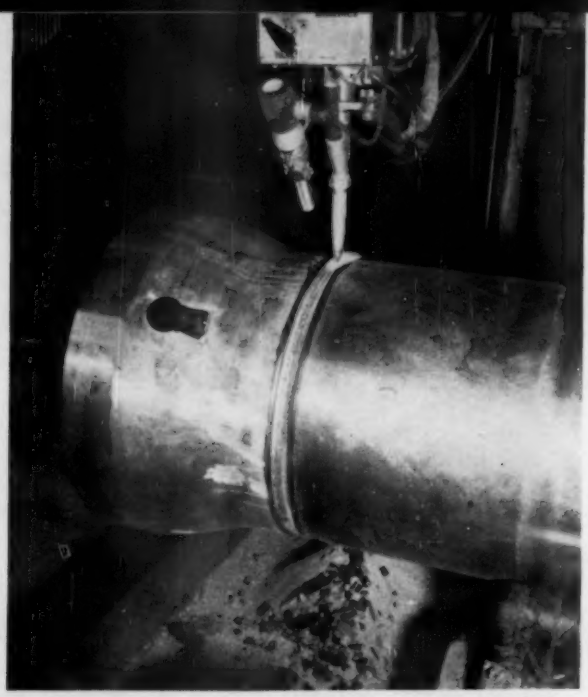

Fig. 7—Automatic submerged-arc welding of stainless Type 304—joining forged pipe with cast fitting—pipe is 20-in. OD by $1^{7}/_{8}$-in. wall

the bend sections were sound, with no thinning below minimum wall requirements.

The shoeing leg was then cut off, the bend section trimmed to length and beveled in preparation for welding.

Welding

Butt joints of the design shown in Fig. 5 were welded by first fusing the consumable insert by the tungsten-arc process with two subsequent layers of weld metal deposited manually. If the weldment could be rotated, the joint was welded by the automatic submerged-arc process; otherwise, the joint was welded manually.

Specifically, the weldment was cleaned by using acetone to remove traces of oil and dust from the surfaces of pipe, fitting and insert. The insert was tack-welded to the pipe side of the joint, the fitting was clamped in position, and dams were placed on the inside to seal off the weld joint. Argon gas was introduced into the section at the rate of 30 cfh for 5 min, and then reduced to 4 cfh for 15 min. A sealing pass was then made by the tungsten-arc process, joining the insert to both sides of the joint. This pass constituted a 100% tack weld rather than a 100% fusion weld—its purpose being to pull the insert tightly to both sides of the bevel. The insert was then fused with the tungsten-arc process.

Whenever possible, a window was provided in the end of the weldment for observation purposes. With the aid of a helper, the operator was able to control his travel speed to avoid unfused insert, "sink," or heavy build-up. Figure 6 shows a manual weld being made by the metal arc process. The window, together with the end seal, is shown clearly. The purge line is also visible indicating that the argon back-up was maintained while two layers of weld metal were deposited by the metal arc process. The welds were made with $^{3}/_{32}$-in. diam stainless Type 308 electrode which deposited a weld containing 6 to 9% ferrite.

The inert-gas dams were replaced by water dams for the completion of the joint. A water line was was set up and water was sprayed against the internal surface of the weld while the dams retained a portion of water to aid in cooling. An interpass temperature of 150–175° F, which was determined by a temperature indicating crayon, was maintained during the automatic welding process. The welding was accomplished with $^{1}/_{8}$ in. diam stainless Type 308 wire, at 230 amp, 28 v and a surface speed of 11 ipm. The thickness of the weld deposit was maintained at $^{1}/_{8}$ in. Figure 7 shows the automatic welding set-up with a joint nearing completion. Figure 8 shows another view of the automatic set-up wherein cooling water is seen draining out of the pipe. Also visible is a portion of the counterbalance used to offset the weight of the cast 90 deg elbow. This counterbalance enabled the weldment to be rotated with a uniform motion. Rubber pads were used to protect the stainless pipe from the chains and drive rolls.

When the procedure qualification test was made for the combination tungsten-, metal- and automatic submerged-arc processes, the test piece had the same wall thickness and OD as the production pipe and was welded by the same welding conditions described earlier. At the time the test was set up, four sets of 3-in gage marks at 90 deg apart were made across the weld joint. Measurements taken at several

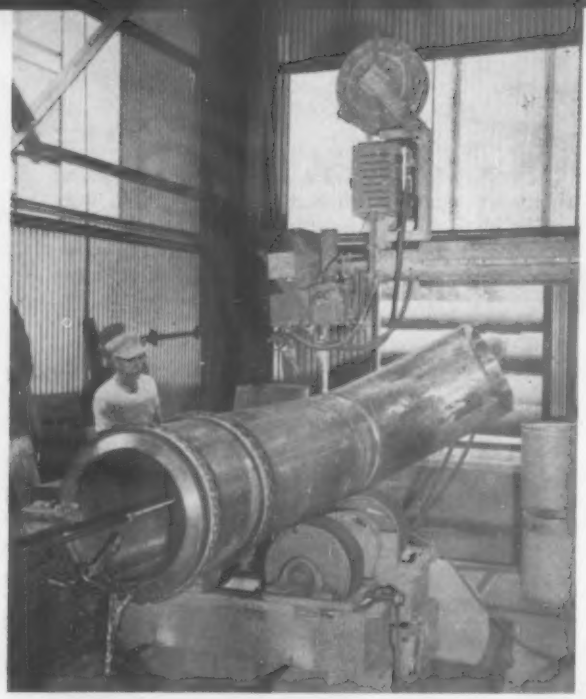

Fig. 8—Automatic submerged-arc welding setup—water is being sprayed on underside of weld to minimize interpass temperature

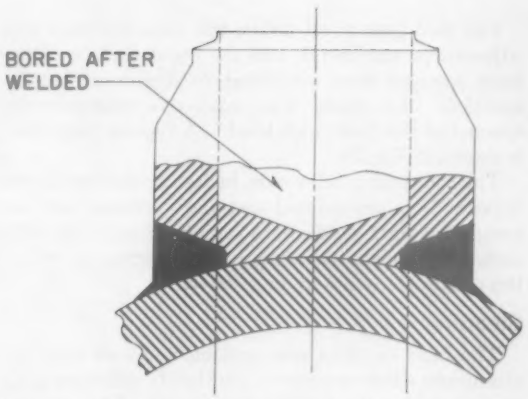

Fig. 9—Typical design of branch connection used on main coolant piping

Fig. 10—Manual metal-arc welding of nozzle attachment to pipe—welding done in overhead position with water back-up to control interpass temperature

stages during the welding operation showed that $^{1}/_{32}$ in. shrinkage occurred after completion of the insert fusion weld with an additional $^{1}/_{32}$ in. shrinkage after each of the first and second manual metal arc welds. By the time the fifth automatic weld layer had been deposited, a total shrinkage of $^{3}/_{16}$ in. had been observed at the level of 1 in. of weld metal thickness. No discernible shrinkage was noted between the 1- and 2-in. levels. On the basis of this information, an allowance of $^{3}/_{16}$ in. for weld shrinkage was made for each butt weld. From a chemical analysis of the test weld, the ferrite content of the weld deposit was determined as between 6 and 10%.

In those instances when it was impractical to rotate the weldment as when the concentric reducers were welded to the bend sections, the entire butt weld was made by the manual metal arc process with the pipe in the horizontal fixed position. Again, water was used to maintain a 250° F maximum interpass temperature.

Nozzle attachments of the design shown in Fig. 9 were likewise welded manually. The design, which eliminates any possibility of lack of fusion at the root requires machining $^{3}/_{8}$ in. from the nozzle ID after it has been welded. One of the attachments is shown in Fig. 10 in the process of being welded, with water being used to maintain interpass temperature. Since the material for the attachments consisted of stainless Type 304, the welds were made with lime-coated stainless Type 308 electrode.

Inspection

All weld surfaces were ground and polished as evidenced in Fig. 11 in preparation for dye-penetrant and radiographic inspection.

Fig. 11—Nozzle attachment weld showing surface finish—all welds ground and polished to a 250 ASA micro-in. finish

The root pass of all welds, the complete weld and adjacent parent metal, and the outer surface of the bend sections were subjected to dye-penetrant inspection. All welds were also dye-penetrant inspected at the 1-in. thick level. A typical inspection is shown in Fig. 12.

The root pass of all welds, including the two layers deposited by the manual metal arc process, and the completed butt welds were radiographed. In addition, all attachment welds were radiographed where the nozzle ID was 3 in. or greater.

Cleaning

The bend sections were grit-blasted with iron-free aluminum oxide to remove the tightly adhering scale formed during the heating operations. The straight sections of pipe, which have a machined ID, were cleaned by swabbing with a chloride-free proprietary solvent.

Immediately after being cleaned, all sections of pipe were capped with end-protectors which were held in place by stainless steel banding. A masonite disk separated the cap from the machined weld bevel. The pipe assemblies were wrapped in heavy paper and strapped onto skids prior to shipment.

Summary

The shop fabrication techniques described in this paper were employed for the stainless steel, primary piping system of the Yankee Atomic Electric Plant. The conventional fabrication practices of bending and joining large sections of piping have proved successful in this application.

Inasmuch as fabrication of nuclear primary piping systems will become more common in the near future, it is axiomatic that quality standards for components and associated weldments in primary piping system must be maintained at high levels.

Fig. 12—Dye-penetrant inspection of weld after completion of fusion pass of consumable insert

Production Welding of Thin-Walled **Pressure Vessels**

for Bomarc missile program presents a unique operation, with four different alloys being gas tungsten-arc welded in a single production shop

BY T. J. BOSWORTH AND D. S. HEMMINGER

Introduction

With the advent of the space age, the development of the thin-walled pressure vessel for missiles became of paramount necessity in order to provide lightweight tanks and cases for liquid and solid propellants. As missile technology advances, stronger and lighter missiles must be designed and built; yet because of these rapid advances, change-overs from one metal to another are not uncommon during the course of a program.

The Bomarc missile program has presented a unique operation, with four different alloys being simultaneously gas tungsten-arc welded in a single production shop. Each alloy has its own fabrication characteristics which affect the welding operations and is reflected into the tooling and processing. For example, 17 – 7 PH stainless steel enlarges during heat treatment, 4330 modified steel, and 2219 aluminum shrink, while 6061 aluminum essentially remain dimensionally uneffected during heat treatment.

Weld Requirements

The Bomarc missile booster and fuel system is comprised of four alloys incorporated into pressure vessels or solid-propellant cases. Table 1 lists the alloys and their composition.

The aluminum alloys operate under essentially low-corrosion conditions in contact with organic fluids. The 17 – 7PH stainless steel operates in contact with high-pressure helium or a highly corrosive fluid, whereas the 4330 modified steel solid-propellant case operates under low-corrosion conditions.

All structural welds are radiographic and dye-penetrant inspected prior to the heat treatment of the assembly, two exceptions being the joining of the 17 – 7PH helium to 17 – 7PH fuel tank, and the attach ring-to-skirt weld on the 4330 modified steel boost-propellant case, both joints being made and inspected after heat treatment. The quality requirements are essentially identical for both steel and aluminum, incorporating visual, penetrant and radiographic methods of inspection. These welds must be free of all visual and penetrant defects such as lack of fusion, pinholes, cracks, undercuts, thinning, cold shuts, overlaps, incomplete penetration and inclusions.

Radiographic inspection of the welds reveal such defects as cracks, incomplete weld penetration, undercutting, concavity, cold shuts, laps or folds and inclusions. Voids, such as porosity, gas holes, cavities and inclusions which do not exhibit sharp ter-

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Paper presented at the 1960 National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

Table 1—Materials of Construction, Bomarc Booster and Fuel System

Aluminum

		Cu	Si	Fe	Mn	Mg	Zn	Cr	Ti	Va	Zr	Other
2219	Max.	6.8	0.2	0.3	0.4	0.02	0.10	...	0.10	0.15	0.25	0.05
	Min.	5.8	...	...	0.2	...	...	...	0.02	0.05	0.10	...
6061	Max.	0.40	0.8	0.7	0.15	1.2	0.25	0.35	0.15	...	...	0.05
	Min.	0.15	0.4	...	...	0.8	...	0.15	...	...	...	...

Steel

		C	Mn	Si	Ph	S	Ni	Cr	Mo	Va	Al
4330 Mod.	Max.	0.38	1.00	1.50	0.025	0.025	2.0	1.00	0.45	0.25	...
	Min.	0.28	0.60	0.50	...	...	1.5	0.65	0.30	0.15	...
17–7 PH	Max.	0.09	1.00	1.00	0.04	0.03	7.75	18.00	...	...	1.50
	Min.	...	...	...	...	...	6.50	16.00	...	...	0.75

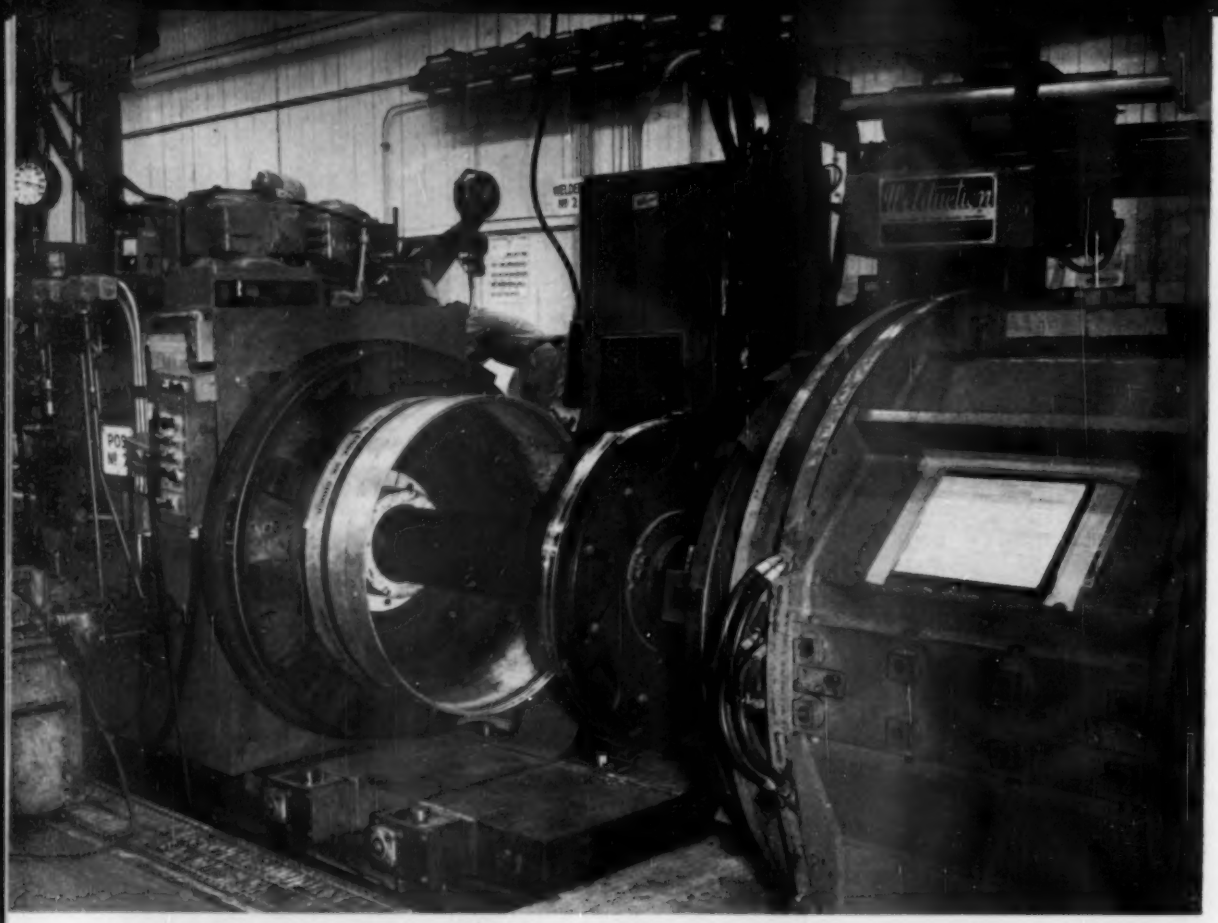

Fig. 1—Lathe-type weld positioner equipped with expanding mandrel

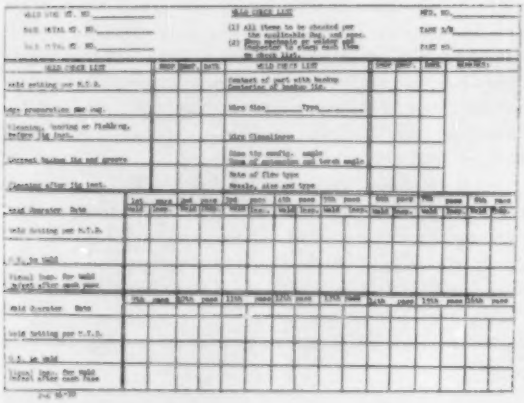

Fig. 2—Quality-control weld-inspection record

mination points are unacceptable when they exceed the following limitations:

1. The greatest dimension of a defect shall not exceed half of the base-metal thickness or .080 whichever is the smaller. Two defects which are spaced closer than the greatest dimension of the smaller defect are treated as one defect.

2. Any accumulation of radiographic defects are rejectable when the sum of their greatest dimension exceeds the limits in Table 2.

Table 2—Acceptable Limits for Radiographic Defects

Base-metal thickness	Maximum total length of defects permitted in 0.5 in. of weld	Maximum total length of defects permitted in 2 in. of weld	Maximum total length of defects permitted in 6 in. of weld
0.20 in. and greater	0.8 times adjacent base-metal thickness	1.6 times adjacent base-metal thickness	3.2 times adjacent base-metal thickness
Up to 0.20 in.	1 times adjacent base-metal thickness	2 times adjacent base-metal thickness	4 times adjacent base-metal thickness

3. Aligned discontinuities or inclusions (four or more) are rejectable when the spacing is less than three times the greatest dimension of the smaller defects.

In addition to the weld-quality requirements listed, the welds are certified at strength values equal to or exceeding the minimum heat-treated base-metal tensile strength with no single test weld being below 97% of the minimum base-metal tensile strength; and must form a bend angle of greater than 35 deg over a 10 T radius. The single exception to this is 4330 modified steel which must withstand a bend angle of 50 deg over a 5 T radius.

Joint Preparation

With the exception of joints which cannot be aligned with tooling or where material thickness is too great (over 0.250 in.), a straight butt joint is used with either single- or double-pass welding in all material. Close-out welds and others which are hard to backup, utilize a self-aligning chevron joint and in heavy-gage materials the chevron joint is combined with either a J or modified-J edge preparation.

Preparation of Parts for Welding

Aluminum

The cleaning of both 2219 and 6061 aluminum consists of both chemicals and mechanical methods. For the most part, however, greater emphasis is placed on the mechanical cleaning of a joint rather than the chemical methods, since mechanical cleaning is performed immediately prior to welding.

The chemical cleaning of 6061 aluminum consists of vapor degreasing, hot-alkaline clean, hot-water rinse, deoxidize for a maximum of 5 min in a hot (160° F) chromic-sulfuric-acid bath, hot-water rinse, and dry. The deoxidation time is maintained at a bare minimum to prevent damage to forgings from grain-boundary attack. In this respect, during early stages of the Bomarc program, parts were heavily etched prior to welding, which resulted in numerous rejections and bad welds. In particular, forgings which contained gross porosity and/or grain boundary precipitates were severely attacked and moisture was left in the voids created, only to be vaporized and entrapped in the weld bead, during subsequent welding.

After several very costly experiences, the deoxidation of parts was minimized and greater emphasis was placed on the mechanical methods of cleaning, using stainless-steel wire brushes and wool. All 6061 parts are chemically cleaned and dried in hot air within 16 hr and not less than 2 hr of welding. The parts are then placed in the positioners, the edges of the joints broken with a file and then the joint area is completely buffed with a stainless-steel rotary brush and steel wool.

Parts fabricated of 2219 aluminum are chemically cleaned in a manner quite unlike the 6061 aluminum. The forged parts are vapor degreased and alkaline cleaned only. Rolled sheet stock is chemically cleaned, including deoxidation, prior to chemical milling, but not prior to welding. Prior to welding, parts are vapor degreased only and then mechanically cleaned in the same manner as the 6061 aluminum parts.

Steel

During the early stages of the program, the cleaning of the 17 – 7PH steel tank components was a combination of chemical and mechanical cleaning. As experience was gained with this alloy, the cleaning operation was revised to vapor degreasing only, followed by sanding and steel wooling the joint edges. The change in the cleaning techniques caused no deleterious effects to the weld.

The cleaning of the 4330 modified steel boost-propellant case weld edges was basically a manual operation from the start of the program. The early cleaning was done with a cone sander which, while it did produce a clean weld edge, required skill in operation to prevent excessive thinning of parts. Later, a grit-blast machine using No. 300 angular steel grit was purchased to replace the cone sanding for joint preparation.

Processing

Each lot or single part that passes through the shop is accompanied by a traveling work order which provides the necessary process information in sequential order. Prior to welding, an inspection check sheet (Fig. 2) is attached to the order which forms a part of the permanent inspection record. All critical information, such as weld settings, weld wire and base-metal heat numbers are checked and recorded by the area inspector. As each operation is completed, both the operator and inspector stamp the check sheet. As welding progresses, the parts are visually inspected between each pass, and any defects removed or repaired. After welding is completed, the weld bead is generally ground and inspected first by visual, penetrant and, finally, radiographic techniques. Generally, repairs are made after the penetrant and radiographic inspections.

With each alloy there have been associated some definite problems which have required special processing techniques to ensure quality performance of the completed assembly. Most notable among these are the problems associated with the 17 – 7 PH tanks. Because slight changes in chemical composition will effect the aging temperature of the alloy, it has been found necessary to check each possible combination of base metal(s) and weld wire for heat-treat compatibility and establish an accurately controlled aging temperature for each tank fabricated. Again, depending upon whether the pressure vessel was heat treated to the TH or RH condition, it was found necessary to alter the weld-wires composition from a 17Cr – 7Ni wire to a 13Cr – 9Ni for structural welds heat treated to the RH condition. Numerous cracks were found to form in the under-bead-filled 17 – 7 welds after heat treating to the RH condition and, since the vessel had no large access to the interior, they were impossible to repair.

During the repair of 17 – 7 forgings or spun section, it was always found that the repair was considerably weaker than the surrounding metal. It was found that laying small amounts of filler wire into the repair cavity and peening while hot, invariably would increase the strength and bend properties to nearly that of the base metal.

The 4330 modified steel tanks are welded using neither preheating or postheating. Prior to the development of the 4330 modified tank, consideration to the merits of whether or not to preheat or postheat were numerous. However, tests showed that there would be no detrimental effects to weld quality if

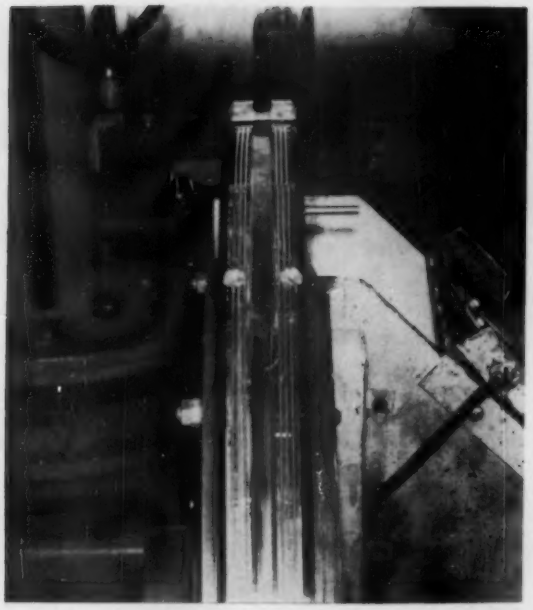

Fig. 3—Mandrel weld-backing shoe used to weld 4330M steel. Mandrel is shown partially retracted thus revealing end view of shoe

the parts were not heated before or after welding and, to date, no failure of this vessel due to weld failure has occurred.

Neither of the aluminum alloys has presented critical processing problems other than was noted under cleaning. At one time in the program, extremely poor welds were encountered on nearly all welds on aluminum but not on steel. Reviewing the operation closely indicated that the contamination level in the helium gas must be maintained below 0.06% for aluminum, but not necessarily that low for steel. As a result, each cylinder of gas is now checked and its purity reverified before its use is allowable.

Welding Tooling

Basic equipment includes lathe-type positioners, tilting-head positioners and mobile, self-contained power supplies and manipulator-mounted tungsten-arc inert-gas-type automatic-welding heads. The controls for the weld positioners and power supplies are integrated, thus allowing the weld operator to initiate positioner starts and stops (including delayed starts or stops, if desired) automatically.

Girth Welding

The girth joints of all tanks are welded in a lathe-type weld positioner. All, except the boost oxidizer and boost-propellant case close-out welds, are welded over an expanding mandrel.

The expanding mandrel is an internal expanding-

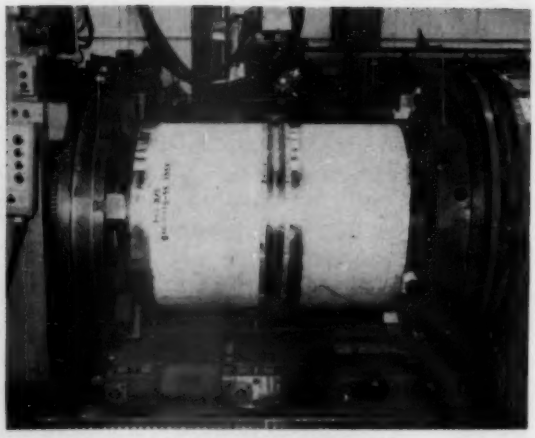

Fig. 4—Aluminum girth-joint set up and ready to weld. Note the external girth bands

type tool with six radially expanding segments. It is mounted on the headstock of a lathe-type weld positioner through its hollow spindle. This is shown in Fig. 1. The mandrel can be axially located to obtain any distance up to 72 in. from the jaws of the head stock chuck.

The expanding mandrel was designed to accept the various weld backing shoes which were made for a specific joint or joints. Figure 3 is a closeup view of the backing used to weld 4330 modified steel on the boost-propellant case. The boost-propellant case utilizes an argon purge to backup the underbead.

If one looks closely at Fig. 3, the stub tube to the right is the means of purge-gas entry to the mandrel. The gas is directed to a manifold (crescent-shaped opening shown at top of the illustration) and from there to the backing groove via very small-diameter holes just discernible along bottom edge of groove.

The weld backing tooling for welding 17 – 7PH steel and both aluminum alloys differ only in the shape of the backing groove. Since a gas purge is not used, the groove configuration is made to conform to what is desired in an underbead cross section. During welding, the underbead is cast into the groove.

The mandrel is powerful in operation, and easily capable of stretching parts to size and this is exactly what is done. Weld shrinkage, and growth or shrinkage through heat treatment of both base metal and weld nugget are factors taken into consideration when designing the backing shoe. This allows the joint to be stretched to the size which will produce a flat surface across the joint after the tank is both welded and heat treated.

It is easy to see the advantages of the expanding mandrel for girth welding. It is fast to set up, versatile in use, provides a perfect matching fit and automatically eliminates separate sizing operations.

Experience has taught that the same materials used to fabricate R&D backing tools for aluminum

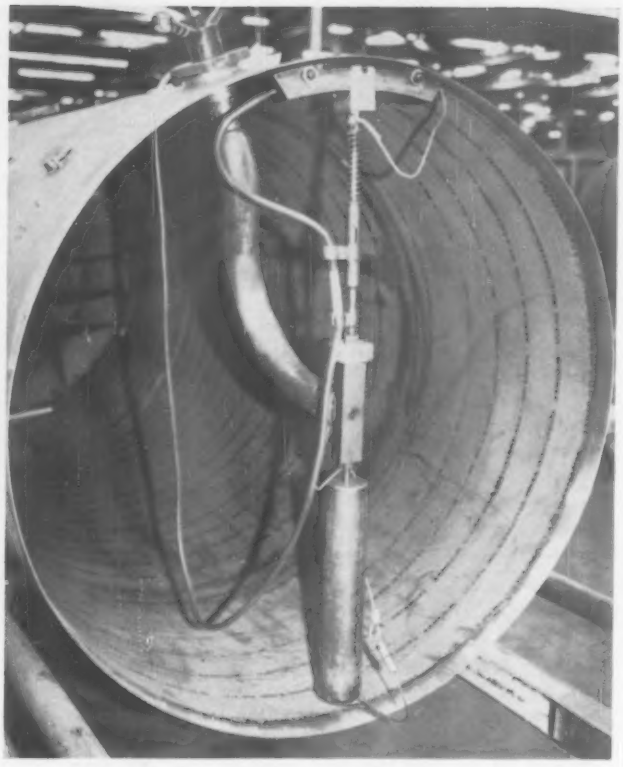

Fig. 5—Close-out weld tooling in place

welding will not work satisfactorily if used to make mandrel backing shoes. It will be of interest and perhaps of some value to the reader to be informed of the experience at the author's plant.

During the R&D program, all backing tooling for aluminum girth welding was made from stainless steel. Tooling was set in place and tightened by hand. Setups were slow but results were satisfactory. All aluminum welds were single pass, giving good results in every way.

Then came production. Production tooling had settled on an expanding-mandrel-type tool for backing girth welds. A prototype of this tool was built, tested and pronounced as a versatile and desirable piece of equipment, as indeed it turned out to be. Since R&D backings were made from stainless steel, it seemed reasonable to make production backing shoes from the same material.

When production began, so did the aluminum welding problems. There was mismatching of parts, lack of penetration in spots and evidence of variable penetration, and worst of all, the stainless-steel backing shoes of the mandrel revealed distortion taking place.

The most serious problem was the warping or distortion of backing shoes. Although it was made of the same material as the R&D tools, the backings were thinner in section, and with repeated welds, the heat of the underbead was such that it caused thermal upset of the backing, resulting in its distortion.

The more intimate contact of part-to-backing brought about by use of the mandrel was responsible for a greater heat sink, thereby causing varying penetration or lack thereof. One other problem not previously mentioned was the adhesion of portions of the underbead to the backing tool. This was caused by the greater pressures between part and backing shoe.

Substitution of chrome-plated copper backing shoes for the stainless steel and recertification of the weld setting from a one-pass to a two-pass weld provided the solution to the distortion and adhesion problems.

The single-pass weld was too sensitive to the heat sink between mandrel and parts, but the change to a two-pass weld reduced the sensitivity to practical limits, thereby eliminating penetration problems.

The process for aluminum circumferential welding, both 6061 and 2219 material, has since run virtually trouble free.

One of the difficulties encountered in the use of the expanding mandrel was due to thermal expansion of the part being welded. Although the parts were stretched diametrically before welding, thus assuring contact with the backing, when nearing weld termination, the part would rise from the backing thus producing poor weld-bead geometry.

The solution to this problem came about by adding two thin, narrow steel bands, one on each side of the joint, allowing only enough space for the torch nozzle to pass—Fig. 4. Bands were tightened prior to mandrel expansion, thus adding their hoop tension to that of the part itself. The restraint was sufficient to hold parts to the backing and many hundreds of satisfactory welds have since been produced.

Boost-propellant case girth welds are not sensitive to thermal expansion because they utilize a gas backup. That portion of the tank shell in contact with the backing tool is far enough removed from the weld zone to preclude its rising from the backing. For this reason, girth bands are not required in the girth welding of 4330 modified steel.

Close-out Weld

The close-out weld of the boost-oxidizer tank is novel from the tooling standpoint. The largest access hole to the inside of the tank is $2^1/_4$ in. in diam; therefore, any tooling used to back up the closure joint must be removed through this hole. The closure weld, a girth joint, is located 6 in. from the center of the hole.

The edge preparation is a self-aligning chevron joint, the mating of which requires accurately machined and properly sized edges to ensure a good fit-up for welding.

Figure 5 illustrates the backing tooling and how it is set up prior to head assembly. Note the sole support for this tool is the goosenecked tube secured

from inside the $2^1/_4$-in. fitting shown at top center left of the illustration. In operation, the goose-necked tube will rotate with the tank, while the remainder of the tool will maintain the vertical position shown by virtue of the pendulum weight seen at the bottom. It is worth mentioning here that the vertical portion of the tool pivots on a remotely controlled retractable stub shaft. The contoured purge cup is spring loaded and rolls against the inside tank surface. Spring loading of the cup ensures a close fit of the purge cup to the inside of the tank even though the stub shaft is not quite accurately centered in the tank.

After the close-out weld is complete and the tool ready to be withdrawn, the stub spindle is retracted by a pull on the wire emerging through the wing-nut stud (just discernible at the top of Fig. 5). If one could see inside the tank after the weld was completed and tool partly removed, Fig. 6 depicts the scene. The illustration shows the gooseneck tube partially removed and clearly shows the connecting cables which make it possible to fish the remaining components through the $2^1/_4$-in. diam hole. The retractable stud spindle is clearly seen protruding from that portion of the gooseneck remaining inside the tank.

Seam Welding

All seam-welding operations utilize the tungsten-inert gas process with the arc maintained on the outside of the shell assembly. One-pass welds are used to weld 17 – 7PH stainless steel, while two-pass welds are used to weld both aluminum alloys and the 4330 modified steel.

From the tooling standpoint, the weld backing bar is the only item which falls in the category of designed tooling. This simplifies design consideration to choice of material and backing-groove configuration. In the case of 4330 modified steel, the backing tool is made of steel with a large gas chamber for purging, very similar to the girth-weld tooling. Similarly the backing tools for the 17 – 7PH stainless steel and the aluminum alloys utilize chrome-plated copper backing bars with grooves similar, if not identical, to those used in the girth tooling.

The equipment used for seam welding is quite conventional. A track mounted automatic tungsten-arc welding head mounted over a backing support bar with hold-down fingers actuated by water pressure.

Fittings-to-shell Welds

Whenever fusion welding is used, the end result always includes some evidence of weld shrinkage. No other weld joint is more sensitive to shrinkage than the fitting to shell welds (circular restraint).

In this category, the 17 – 7PH stainless steel thin-wall shell to fitting weld was a major problem. Distortion could not be contained within usable limits even when the heaviest of restraint tooling was used.

The problem was resolved by fabricating the cylindrical shell section into two pieces, one piece being large enough to contain the fittings (referred to as a patch) and the other piece completing the shell. Figure 6 shows two fittings welded into a patch and the patch welded into the completed tank.

The fittings were welded to an oversized patch, the resulting distortion removed with a stretch press operation, and the patch trimmed and welded (via seam welds) into the shell subassembly. An X-ray and dye penetrant inspection of the welds were, of course, required.

The same type of joint on aluminum was not troublesome because of the thicker material and deep chem-milled edges which provided the strength to resist the weld shrinkage.

Fittings to shells, heads or patches are automatically welded utilizing a merry-go-round type of tool as shown in Fig. 7. The illustration depicts the set-up for welding a fitting to a chem-milled 6061 aluminum shell, the same tool with different fixturing is used to automatically weld other similar joints.

Head-to-"Y"-ring Weld

Three tanks, both 2219 and 6061 aluminum, and the boost-propellant case utilize forgings machined to a "Y" configuration, used as a transitional structure member at the junction of the shell to head. Assembly of the "Y" ring, as it is called, begins by welding the tank head to the "Y" ring. All of these welds are welded from what will eventually be the inside of the tank. Figure 8 illustrates a tilt-head positioner with weld jig mounted complete with welded assembly. The manipulator-mounted automatic gas tungsten-arc head has been raised and is visible near the top of the picture. The completed two-pass weld is observed directly below the weld torch. Resting on the floor and propped against the weld jig are two unwelded 4330 modified steel parts, identical to those which make-up the completed head assembly in the weld jig. The weld backing-groove dimensions are similar to those used for girth and seam welding.

Similar fixturing and tooling is used to weld the heads and "Y" rings of the Ramjet aluminum tanks.

The boost-oxidizer head assembly does not utilize a "Y"-ring forging. Instead, the head is spun from one piece of material to the full size of the tank.

About 2 in. from the open end of the head, a joggle is provided to allow a skirt of the same diameter as the tank to slide in place. The skirt is spot welded to the tank head at the joggle area. The spot welds can be seen just to the right of the extreme right-hand girth weld in Fig. 9. After spot welding, the skirt is fusion welded to the head (extreme right-hand girth weld in Fig. 9).

Hand Welding

The inert-gas-shielded tungsten-arc process is

Fig. 6—Illustrating the removal of close-out weld tooling

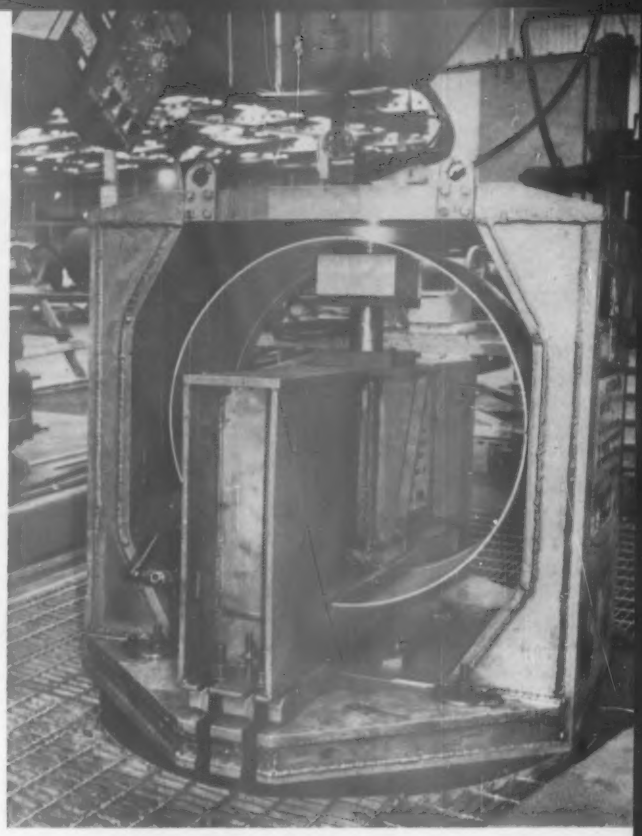

Fig. 7—Merry-go-round positioner and fixture with 6061 aluminum shell-to-fitting setup

Fig. 8—Tilting-head positioner and weld jig for assembling boost-propellant case "Y" ring to head

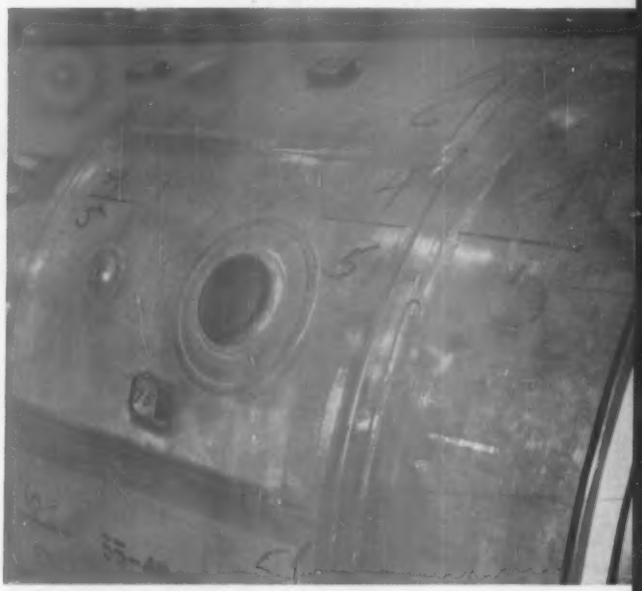

Fig. 9—Illustrating fitting-to-patch welds with 0.100 in. 17–7PH steel

used almost exclusively for hand welding. The exception was brought about because of distortion problems resulting from the tungsten-arc welding of fairing clips to the Ramjet tank. The inert-gas-shielded metal-arc process is now employed with excellent results.

Hand welding is applied to such assemblies as clips, baffles, tubing, small brackets and other assorted items which could not be welded practically on the automatic machines.

Constricted tungsten-arc cutting being applied to 1-in. thick stainless steel wherein a shielding gas flow of 200 cfh results in a dross-free cut

Advances since 1955 are described whereby high quality cuts in 4-in. thick stainless steel and 5-in. thick aluminum are among potentials realized with the

Heavy-Duty Constricted **Tungsten-Arc Cutting** of All Metals

BY W. A. GEIDEMAN AND H. B. BOTT

As originally introduced to industry in 1955, constricted tungsten-arc cutting was confined to just one metal—aluminum. Its use on copper and magnesium followed soon afterwards, and laboratory tests indicated possible application to stainless steel and nickel.[1] More recently, its potential for stainless steel was confirmed on a production basis during the cutting of shapes in warehousing operations.[2]

In all of this work, constricted tungsten-arc cutting has been subject to thickness limitations. Initially, for example, the maximum thickness of either aluminum or magnesium that could be cut with the process was $1^1/_2$ in. As a result of relatively recent developments, however, all metals to which constricted tungsten-arc cutting may be applied can be cut beyond their original thickness limitations by what is described as "heavy-duty cutting."

The maximum thickness of either aluminum or magnesium now being cut on a production basis with the constricted tungsten-arc process is 3 in. For other metals, the maximum thickness is 2 in. Thus heavy-duty cutting is widely used in the fabrication of parts made from $1^1/_2$- to 3-in. thick aluminum or from other metals ranging in thickness from 1 to 2 in. For example, heavy-duty cutting is being used in the fabrication of aluminum tank cars, for the aluminum superstructure on ships now under construction, and in the fabrication of stainless steel for use in nuclear reactors.

Still greater thicknesses of up to 5 in. in aluminum and 4 in. in stainless steel or other metals can be cut

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through the use of higher voltages and high gas flows. As a consequence, what can be termed "normal heavy-duty cutting" may be supplemented by "high gas flow heavy-duty cutting."

Normal Heavy-duty Cutting Requirements

Equipment and Operation

Heavy-duty cutting begins at $1^1/_2$ in. for aluminum and magnesium and at 1 in. for other metals. In this respect normal heavy-duty cutting, which involves the use of gas flows of approximately 100 cfh, will cut aluminum up to 3 in. thick and stainless steel and other metals up to 2 in. thick. However, recent laboratory experimentation with higher gas flows in the order of 200 cfh has shown that these thickness limitations can be eased and that up to 5-in. thick aluminum and other metals up to 4 in. thick may be cut. Furthermore, it is possible to eliminate the dross on stainless steel up to $1^1/_2$ in. in thickness.

Normal heavy-duty cutting obviously calls for certain equipment as illustrated by the typical mechanized heavy-duty constricted tungsten-arc installation in Fig. 1. The torch is shown in the foreground and is mounted on a machine carriage. The cutting control is mounted on the wall to the rear of the installation. Next to the control is a cylinder containing a mixture of 65% argon and 35% hydrogen along with the pressure regulator and flowmeter. Located on the track at the right is a remote control box, which is used for starting the cutting operation and which also provides a travel switch and an energency stop push button. In this instance, the torch is shown with a piece of 3-in. thick aluminum.

The operator chooses his cutting conditions by setting his power supply to give him the current and voltage required and by choosing the proper speed for the thickness of plate which he is cutting and the power he is using. He then positions the torch at the edge of the plate with the end of the torch approximately $^1/_4$ in. from the top surface of the plate. He then pushes the start button, and cutting starts instantaneously. At the end of the cut, the arc automatically shuts itself off and the equipment is ready for the next cut.

The equipment shown in Fig. 1 differs from that used in manual heavy-duty cutting only in that a different torch—namely, a manual torch—is used and in that another cutting control providing a different pilot-arc circuit is employed. In the case of manual cutting, a push button is located on the handle of the torch to start the pilot arc. After the operator initiates the pilot arc, he then lowers his helmet, and the pilot arc acts as a light so that he can see the scribe line or the point where he wants to start cutting. He then proceeds to bring the torch down. As soon as the torch is close enough to the workpiece, the main arc is initiated automatically and the operator proceeds to make his cut. After the cut is finished, he raises his torch from the work and the arc is automatically extinguished.

Manual heavy-duty cutting has introduced differences with respect to the shielding-gas mixture. The manual cutting of under $1^1/_2$-in. thick aluminum and magnesium and under 1-in. thick stainless steel calls for a gas consisting of 20% hydrogen and 80% argon. In manual heavy-duty cutting, a mixture of 35% hydrogen and 65% argon is used. In both instances, however, two separate cylinders are required since argon flow must precede the hydrogen flow.

Current Requirements

Sufficient power is the key to successful heavy-duty constricted tungsten-arc cutting. Normal heavy-duty cutting requires the use of currents exceeding the 400 amp previously employed. Thus it has been found that a power supply capable of delivering 700 amp at up to 100 v must be used to cover the range of normal heavy-duty cutting. In this respect, Fig. 2 shows the maximum cutting speeds that can be obtained in the cutting of aluminum using currents varying from 400 to 700 amp.

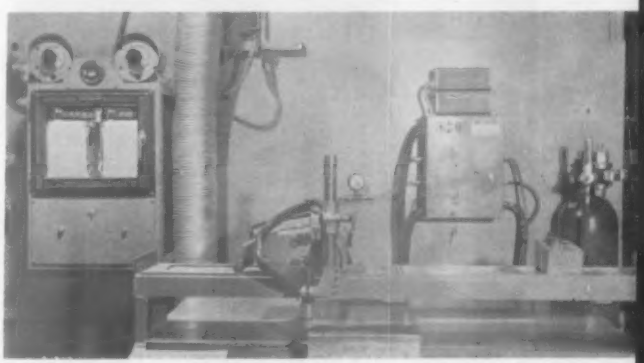

Fig. 1—Equipment for heavy-duty constricted tungsten-arc cutting (also shows appearance of 3-in. thick aluminum plate immediately after cutting)

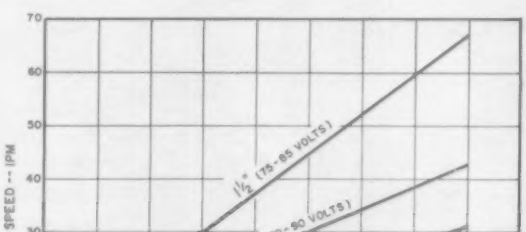

Fig. 2—Maximum cutting speeds for $1^1/_2$- to 3-in. thick aluminum plate

As the current is increased, the cutting speed is increased. Thus for the heavier thicknesses such as 3-in. thick aluminum, it is necessary to use approximately 700 amp to get a good quality cut.

Figure 3 shows the power supply requirements needed to achieve 700 amp at 100 v. As may be seen, two 600 amp rectifiers or two 600 amp generators will enable the full range of cutting speeds to be realized for $1^1/_2$-in. thick aluminum. For 2-in. thick aluminum, two 600-amp motor generator units will enable the full range of travel speed to be realized. While two 600-amp rectifiers will not give the full range, they will cover most of it. In the case of $2^1/_2$-in. thick aluminum, the two 600-amp motor generator units will cover the full range of cutting speeds for this thickness. However, the two 600-amp rectifiers will enable only approximately $^2/_3$ of the maximum speed to be realized. In the case of 3-in. thick aluminum, a combination of two 600-amp generators or a combination of one 400 and one 600 amp generator in series are the only two combinations that will enable cutting of this thickness. In all cases listed, a combination of two power supplies means that they are connected in series.

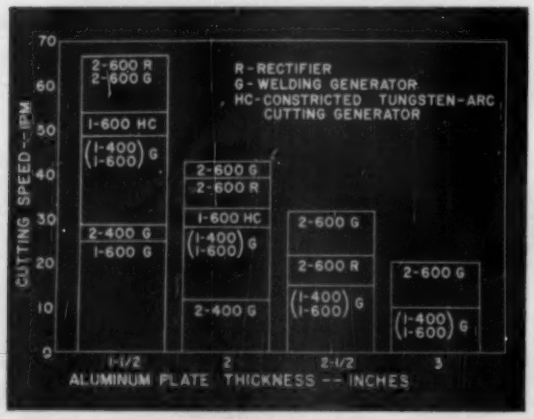

Fig. 3—Power supply requirements for heavy-duty constricted tungsten-arc cutting

Operating Problems and Their Solution

The use of higher currents introduced operating problems, which had to be solved before heavy-duty cutting could be carried out successfully. Since it was necessary to connect two power supplies in series to achieve these higher currents at the voltages used, this introduced a further problem in that high open circuit voltages were present. In addition, the high-cutting current of up to 700 amp also produced problems in the life of the cutting insert and in the life of the tungsten electrode.

These problems were solved in part by making a larger diameter insert and by using larger diameter thoriated tungsten electrodes. The use of higher water flows for cooling also prolonged insert life at these high currents.

Figure 4 shows the accessories needed to convert a standard cutting setup, which can be used up to 400 amp, for normal heavy-duty cutting. The lower left hand corner shows the collets for both mechanized and manual torches; also shown is a $^5/_{32}$-in. diam 2% thoriated tungsten electrode which is used to carry the 700 amp. The lower right hand corner illustrates the extra water hoses, the extra resistor for the pilot arc circuit, various mounting brackets for this resistor and the new larger diameter insert. The actual conversion is easily carried out.

Cooling Water Requirements

To provide the greater water flows necessary to

Fig. 4—Accessories for converting standard cutting set up for use in heavy-duty cutting

Table 1—Conditions for Normal Heavy-duty Cutting[a]

Metal	Plate thickness, in.	Current, amp	Volts	Gas[b] flow, cfh	Speed, ipm
Aluminum	1 1/2	700	83	100	60
	2	700	87	100	35
	2 1/2	700	92	100	25
	3	700	96	100	20
Stainless Steel	1	500	80	100	25
	1 1/2	600	80	100	20
	2	700	85	100	15

[a] Cutting is carried out with torch having 1/16-in. diam orifice and 1/32 in. diam 2% thoriated tungsten electrode.
[b] Gas consists of mixture of 35% hydrogen and 65% argon.

maintain torch life at 700 amp, a water pump is used since water flow must be at least 6 qt/min to maintain adequate torch operation continuously. Measurements were made to determine the heat input to the cooling water as a function of current in constricted tungsten-arc cutting. Figure 5 shows the rate at which heat input to the water increases as the current is increased. As can be seen, at 700 amp the heat input to the cooling water is approximately 19,000 Btu per hour, which is about 5% of the total arc power. In order to keep the water temperature at a reasonable level, it is necessary to have a flow of 6 qt/min to dissipate this amount of heat without damaging the cutting orifice.

Shielding Gas

Development on normal heavy-duty cutting revealed that a mixture of 35% hydrogen and 65% argon was satisfactory for both manual and mechanized heavy-duty cutting. This is in contrast to the mixture of 20% hydrogen and 80% argon used for manually cutting aluminum less than 1 1/2 in. thick and less than 1-in. thick stainless steel.

In normal heavy-duty cutting, gas flows of approximately 100 cfh total flow are adequate for all thicknesses which are encountered. However, it is still necessary in manual cutting to use separate cylinders of argon and hydrogen, since conventional pilot arc starting methods for manual operation are used in normal heavy-duty cutting. The use of separate gas cylinders is necessary, since the pilot arc is stable only in argon and cannot be maintained in a mixture of 35% hydrogen and 65% argon. Thus the separate cylinders provide argon for the pilot arc as well as both argon and hydrogen for the actual cutting operation.

Operating Conditions

Selection of Operating Conditions

Table 1 shows typical operating conditions for the normal heavy-duty cutting of aluminum and stainless steel. This table lists the cutting current, the arc voltage, the cutting speed and the gas flow that are used for the different thicknesses. Thus if an operator wishes to cut 2 1/2-in. thick aluminum plate, he should first determine what his power condition would be —namely, can he obtain the 700 amp at 92 v necessary to cut this material? Assuming that the necessary current and voltage are available, he will then select his cutting speed (in this case, 25 ipm) and set his gas flow to 100 cfh. At this point, the operator would be ready to proceed with actual cutting.

If the power supply setting is indefinite and the operator does not know whether he will attain the proper current and voltage at the selected setting, it will generally be wise for him to make a practice cut and adjust his power settings during cutting to achieve the conditions listed in the table.

Arc Starting

As previously mentioned, development on heavy-duty cutting revealed that conventional pilot-arc starting methods for manual operation may be used. On the other hand, it was found that independent control of the travel carriage was sometimes required in mechanized operation when cutting thick plate. In some instances, it has been found necessary to manually turn the travel carriage on and off while waiting for the arc to penetrate the thickness of plate being cut.

As soon as the arc has penetrated the full thickness of the plate, the travel carriage is started and cutting continues as in normal operations. It is generally necessary to turn the travel carriage on and off, since the arc will not usually penetrate the full thickness of the plate while resting over the edge of the plate. It is necessary to have some metal near the torch or the arc will extinguish itself. In many instances, however, just a slight delay to the starting of the travel carriage (in some cases no delay at all) is necessary when starting. It is only when cutting close to the maximum thicknesses that this starting technique need be employed.

Safety

Figure 6 shows an operator making a manual cut in 2-in. thick aluminum plate. In addition to the normal precautions necessary for standard cutting—namely, gloves, eye protection, etc.—it is necessary

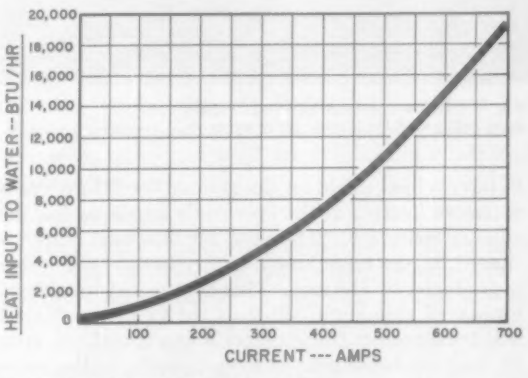

Fig. 5—Heat absorbed by water during constricted tungsten-arc cutting

Fig. 6—Manual cutting with heat shield on torch

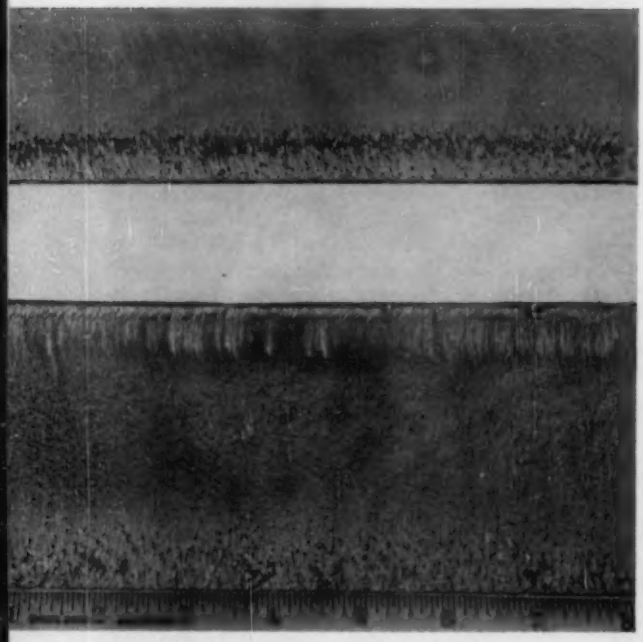

Fig. 7—Mechanized constricted tungsten-arc cuts in 2- and 3-inch thick aluminum

to have a heat shield on the manual torch to prevent excessive heating of the operator's hands during the cutting operation. The need for this heat shield is caused by the large amount of radiated heat which is produced by the arc. This heat shield consists of a piece of aluminum, which is cut to size so that it will both protect the operator's hands and not drag on the plate being cut. It mounts easily on the torch through the use of a simple bracket, which can be welded to the aluminum sheet.

Fig. 8—Manual contour constricted tungsten-arc cuts in $1^1/_2$- and $2^1/_2$-in. thick aluminum

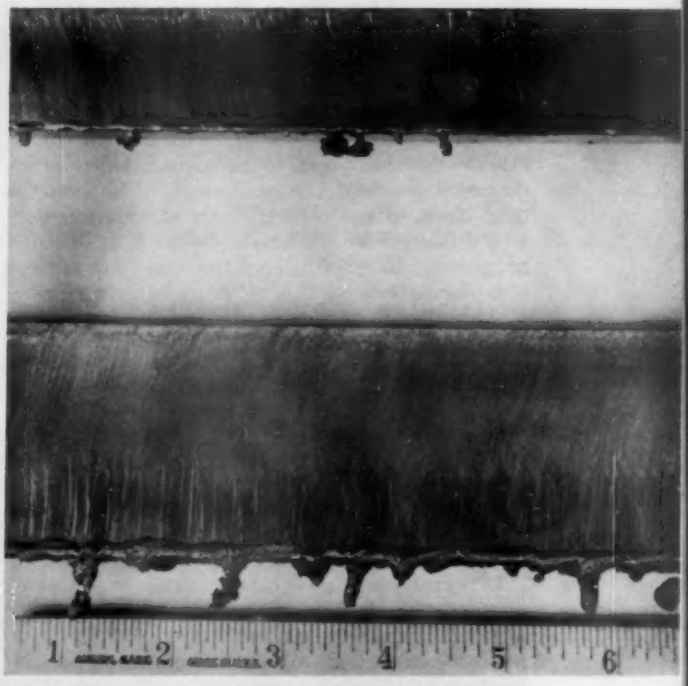

Fig. 9—Mechanized normal heavy-duty constricted tungsten-arc cuts in 1- and 2-in. thick stainless steel

Because heavy-duty cutting involves high gas flows and a high-intensity arc, it is sometimes necessary for the operator and others in the vicinity of the cutting operation to wear some type of ear protection. Ear protection can be provided in the form of ear plugs which will eliminate most of the sound. Also care should be taken by the operator to protect himself from the hazards of the higher open-circuit voltage required in heavy-duty cutting.

As in all other welding and cutting operations, it is also advisable to have adequate ventilation or to provide an exhaust system to remove fumes that are produced in the cutting operation. In general, a building with a high ceiling provides sufficient ventilation.

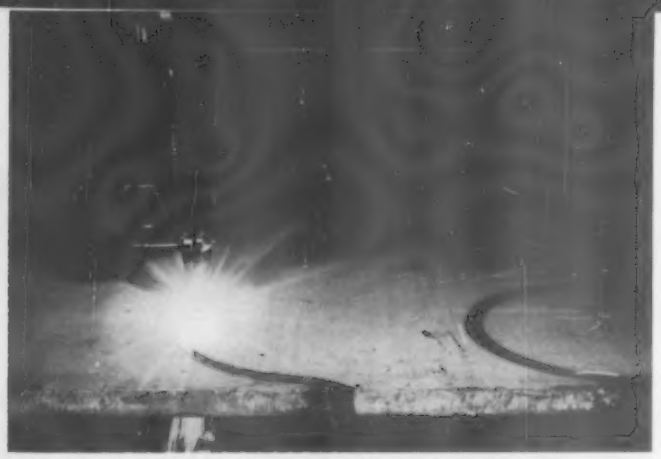

Fig. 10—Circle cutting in $1^1/_4$-in. thick Type 305 stainless steel

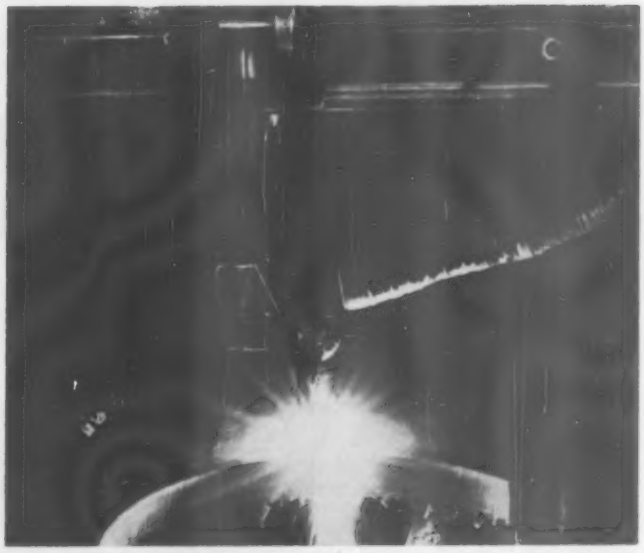

Fig. 11—Circle cutting in $1^1/_2$-in. thick Type 305 stainless steel

Results of Normal Heavy-duty Cutting

Aluminum

Figure 7 shows mechanized cuts in 2- and 3-in. thick aluminum made using the cutting conditions in Table 1. The quality of these cuts is comparable to that obtained on thinner aluminum. The kerf wall is smooth, and there is no dross or slag adherence to the kerf. On the thicker materials—namely $2^1/_2$- and 3-in. thick aluminum—there is a concavity to the kerf wall which is caused by the shape of the arc and which occurs for about 1 in. from the top of the piece being cut. The rest of the cut is straight.

Figure 8 shows manual contour cuts in $1^1/_2$- and $2^1/_2$-in. thick aluminum. Here again, the quality of the cut is comparable to that obtained in cutting thinner materials. Attached dross or roughness to the kerf is no more than that caused by the operator. Again, there is a slight saucer-like effect in the heavier thickness as encountered in machine cutting.

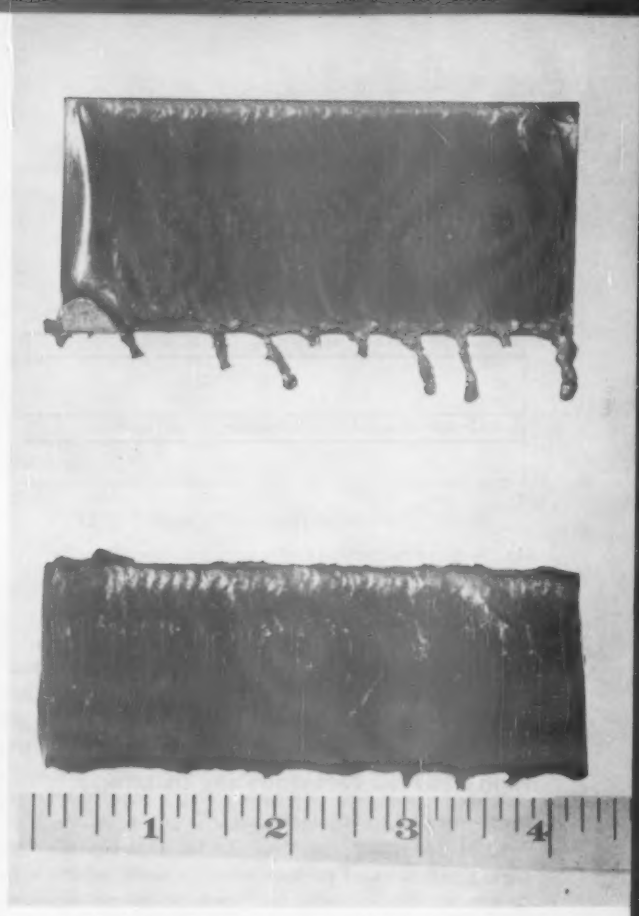

Fig. 12—Mechanized heavy-duty constricted tungsten-arc cuts in $1^3/_4$-in. Inconel (top) and $1^3/_4$-in. stainless steel (bottom)

Stainless Steel

Figure 9 shows cuts made in 1- and 2-in. thick stainless steel, using normal heavy-duty constricted tungsten-arc cutting. The quality of these cuts is the same as that obtained on thinner materials. A smooth kerf is made with dross adhering to the lower edge of the kerf. This dross is quite tenacious and must be removed by using an air chisel and by grinding. No more dross forms in normal heavy-duty cutting than in the standard cutting of thinner materials. Figures 10 and 11 show a typical installation for heavy-duty constricted tungsten-arc cutting in a warehouse operation. In Fig. 10, circles are being cut from $1^1/_4$-in. thick Type 305 stainless steel. Similarly in Fig. 11, circle cutting is being carried out in $1^1/_2$-in. thick Type 305 stainless steel; the quality of cut obtained is illustrated in the foreground.

Process Versatility

Heavy-duty constricted tungsten-arc cutting may be applied effectively to all metals. Magnesium is cut with about the same resulting quality and at about the same conditions as aluminum. Other metals may be cut by using the conditions given in Table 1 for stainless steel. In the cutting of copper, however, no dross is formed.

Figure 12 illustrates two cuts—one in $1^3/_4$-in.

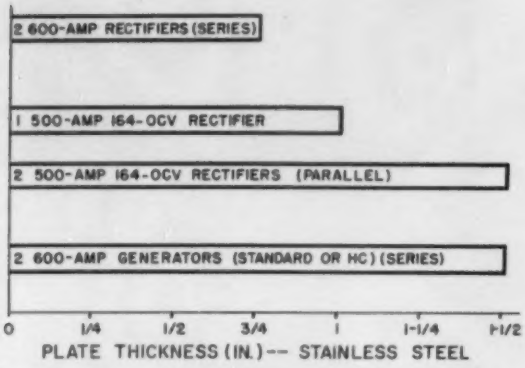

Fig. 13—Some suggested power-supply combinations for high gas flow dross-free cutting of stainless steel

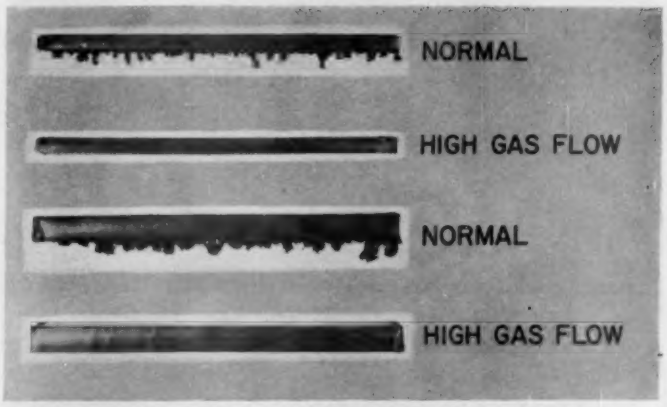

Fig. 14—Comparison of normal and dross-free cuts in $^1/_2$- and $^3/_4$-in. thick stainless steel

thick Inconel plate and the other made in $1^3/_4$-in. thick stainless clad steel. The quality illustrated here is obtained in other metals such as Monel and copper clad steel. Heavy-duty cutting can also be applied to nickel and high-alloy steels.

High Gas Flow Technique and Its Effects

Dross-free Cuts in Stainless Steel

Recent development has shown that the use of high gas flows and pressures in the order of 200 cfh of gas at 40 psi regulator pressure in conjunction with higher powers and smaller diameter inserts than used in normal cutting will produce dross-free cuts in stainless steel and other metals up to $1^1/_2$ in. thick. This form of cutting is illustrated in the lead photograph where a mechanized cut is being made in 1-in. thick stainless steel. As may be seen there is no dross adhering to the lower edge of the kerf on either side of the cut. This particular cut is being made at a cutting speed of 25 ipm using 360 amp and 115 v.

The power supply used in making this cut was a rectifier having a 500-amp capacity with an open circuit voltage of 164 vs—Fig. 13. The conditions under which dross-free cuts are obtained in other thicknesses of stainless steel and similar metals are shown in Table 2. One thing to note in referring to

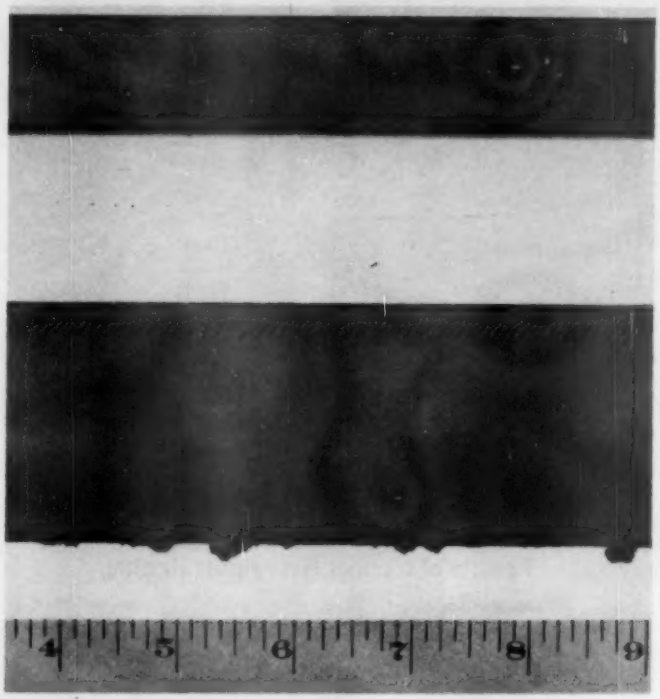

Fig. 15—Mechanized high gas flow cuts in 1- and 2-in. thick stainless steel

Table 2—Conditions for Dross-free Cutting of Stainless Steel

Thickness, in.	Current, amp	Volts	Speed, ipm	Regulator pressure, psi	Gas[a] flow, cfh	Orifice[b] diameter, in.
$^3/_8$	420	105	70	40	200	$^1/_8$
$^1/_2$	380	107	60	40	200	$^1/_8$
$^3/_4$	380	110	35	40	200	$^1/_8$
1	360	115	25	40	200	$^1/_8$
1	600	110	30	40	200	$^5/_{32}$
$1^1/_4$	600	113	25	40	200	$^5/_{32}$
$1^1/_2$	620	115	20	40	200	$^5/_{32}$

[a] Gas consists of mixture of 35% hydrogen and 65% argon.
[b] Electrode diameter equals orifice diameter.

Table 2 is that the voltage in all instances is much greater than that shown in Table 1 and greater than those used for thinner material in standard cutting. The higher voltage is caused by the use of the smaller diameter inserts in conjunction with the high gas flows. The current used and the travel speeds obtained are similar to those achieved in standard cutting.

Significance for Stainless-Steel Fabricators

Figure 14 compares cuts made in $^1/_2$- and $^3/_4$-in.

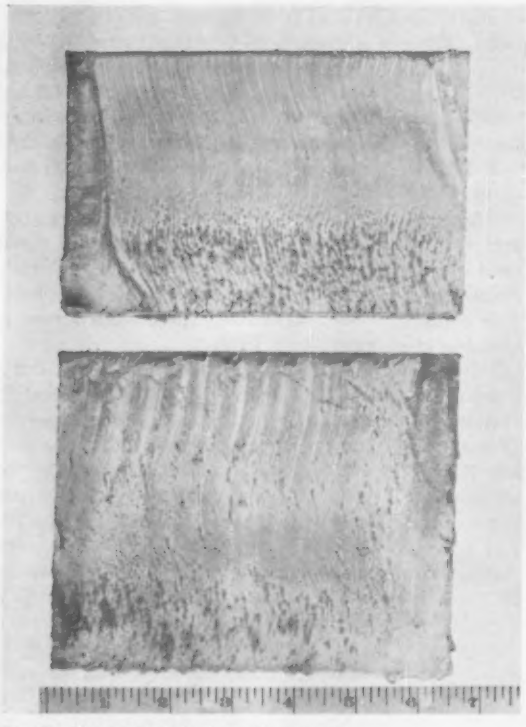

Fig. 16—Mechanized high gas flow cuts in $4^1/_4$- (top) and 5-in. (bottom) thick aluminum

thick stainless steel. One cut in each thickness was made using the high gas flow technique, and the other cut was made using standard techniques. The use of high gas flows producing dross-free cuts in material where standard conditions produced dross means that the user of the tungsten-arc cutting process can eliminate one step in his fabrication—namely, the removal of the dross by mechanical means. Of course, on metals where dross does not form using standard conditions and techniques, there is no need to use high gas flows and high power.

Tests have shown that dross is not eliminated even at high gas flows when speeds substantially less than those shown in Table 2 are used. Although low speeds result in less dross than standard techniques, the dross is still present and its mechanical removal is still necessary.

Figure 15 shows mechanized cuts made in 1- and 2-in. thick stainless steel using the high gas flow high-power technique. The quality of these cuts is superior to the quality of cuts shown in Fig. 9 wherein normal heavy-duty cutting techniques were employed. In the case of the 1-in. thick stainless steel, there is no dross when using the high gas flow technique while there is an appreciable amount of dross using the standard technique. In the case of the 2-in. thick stainless steel, the cut quality is much improved using the high gas flow technique in that

Table 3—Conditions for High Gas Flow Heavy-duty Cutting[a]

Metal	Plate thickness, in.	Current, amp.	Volts	Speed, ipm	Regulator pressure psi	Gas[b] flow, cfh
Aluminum	3	700	130	20	40	200
	$3^1/_2$	700	145	15	40	200
	4	700	155	13	60	300
	$4^1/_2$	700	160	10	60	300
	5	700	170	8	60	300
Stainless steel	2	700	120	20	40	200
	$2^1/_2$	700	125	15	40	200
	3	700	130	12	40	200
	$3^1/_2$	700	140	9	40	200
	4	700	160	5	60	300

[a] Cutting is carried out with torch having $^1/_{16}$-in. diam orifice and $^1/_8$-in. diam 2% thoriated tungsten electrode.
[b] Gas consists of mixture of 35% hydrogen and 65% argon.

the concavity of the kerf wall is much less and in that there is a smaller amount of dross than obtained with standard cutting conditions.

In all cases, the use of high gas flows and high power for cutting thick material will produce a kerf wall, which is straighter and has less concavity than obtained using standard conditions. Also in the case of stainless steel and nickel alloys and other dross forming materials, there is less dross than when using standard or normal conditions—that is to say, at thicknesses of $1^1/_2$ in. and below dross can be eliminated.

Application to Aluminum

As an extension of the development of the dross-free cutting technique for stainless steel, the use of high gas flows and high-regulator pressures in the cutting of thick aluminum enables greater thicknesses to be cut without exceeding 700 amp. Figure 16 shows mechanized cuts made in $4^1/_4$- and 5-in. thick aluminum. The conditions at which these cuts were made are given in Table 3.

As can be seen in Fig. 16, the quality of high gas-flow cuts in aluminum is similar to that obtained using standard techniques—except that there is less concavity to the kerf wall than obtained using standard gas flows. It will be noted in Table 3 that 300 cfh of gas at 60 psi regulator pressure was used in cutting 4-in. thick and over aluminum. This was found necessary since use of 200 cfh of gas at the 40 psi regulator pressure produced a rough kerf surface, while gas flows above 300 cfh at pressures higher than 60 lb did not improve the quality of the cut.

The maximum thickness of aluminum that can be cut using high gas-flow technique is 5 in. Although greater thicknesses can be severed, cut quality is much inferior to that shown for the 5-in. thick sample in Fig. 16.

Over-all Thickness Limitations

Thickness limitations for the high gas-flow cutting

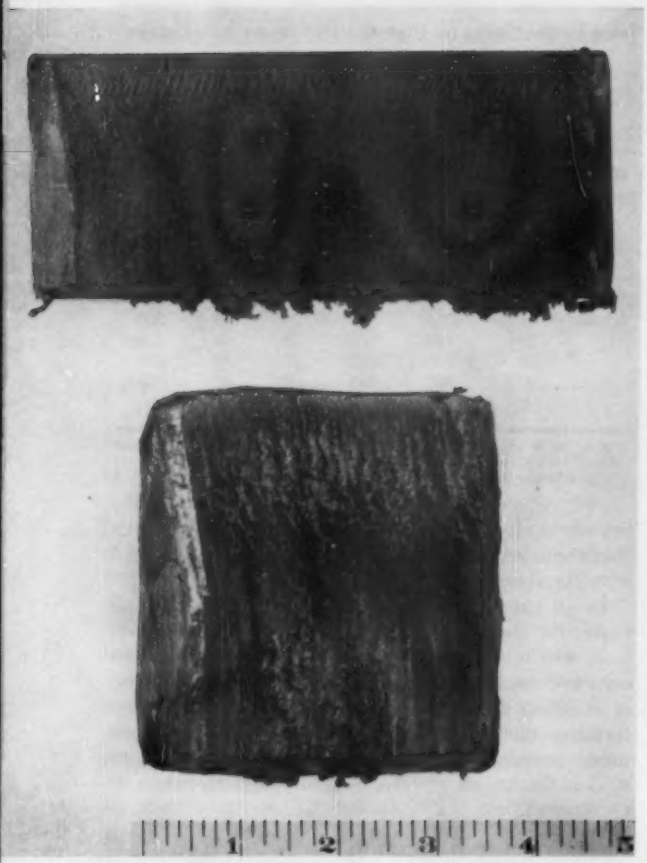

Fig. 17—Mechanized high gas flow cuts in $2^1/_2$- and 4-in. thick stainless steel

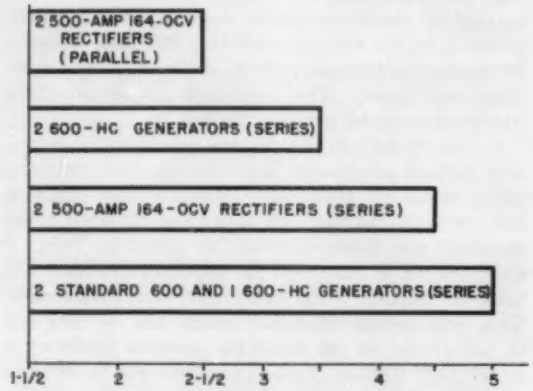

Fig. 18—Some power-supply combinations for high gas flow heavy-duty cutting

of stainless steel and other metals are slightly less than presently encountered for aluminum—namely a maximum of 4 in. As can be seen in Table 3, the cutting speeds are somewhat less when cutting stainless steel than for cutting aluminum at the same thickness. The thickness limitation again is imposed by the maximum current that the torch can carry.

Figure 17 shows typical mechanized cuts in $2^1/_2$- and 4-in. thick stainless steel. The quality of these cuts is similar to that obtained in thinner material. Some dross is formed at the low edge of the kerf. The conditions used in cutting these thicknesses of stainless steel are given in Table 3.

Power requirements for high gas-flow heavy-duty cutting are much greater than required for normal or standard heavy-duty cutting. Some suggested power supply combinations for this form of cutting are shown in Fig. 18. These combinations apply equally to all metal thicknesses up to the maximum for a specific combination *or* for a specific material. For example, the two 500-amp 164 OCV rectifiers in parallel may be used on up to $2^1/_2$-in. thick aluminum or stainless steel. The same rectifiers in series may also be used on all metals up to 4 in. thick but may not—except in the case of aluminum—be used on metal thicknesses exceeding 4 in.; in the case of aluminum, the maximum thickness is $4^1/_2$ in. In all instances, the maximum current that can be carried safely in present torches is 700 amp.

Summary

Heavy-duty constricted tungsten-arc cutting is best carried out using a gas mixture of 35% hydrogen and 65% argon. When using high gas flows of 200 cfh and over, it is possible to cut aluminum and magnesium up to 5 in. in thickness and stainless steel and other metals in thicknesses up to 4 in. DCSP current up to 700 amp must be used. With gas flows of 100 cfh and at 700 amp, the maximum thicknesses that can be cut is reduced to 3 in. for aluminum and 2 in. for stainless steel.

Dross invariably forms during the normal heavy-duty cutting of stainless steel and certain other materials. Dross-free cuts are produced, however, on stainless steel thicknesses up to $1^1/_2$ in. when high gas flows are employed. Furthermore, the use of high gas flows both reduces dross formation and improves cut quality in the greater thicknesses.

References

1. Oyler, G. W., O'Brien, R. L., and Maier, J., III, "Constricted Tungsten-Arc Cutting of Aluminum," THE WELDING JOURNAL, 35 (12), 1214–21 (1956).

2. Wait, J. D., and Rash, S. H., "Tungsten-Arc Cutting of Stainless Steel Shapes in Steel Warehousing Operations," *Ibid.*, 38 (6), 576–81 (1959).

Spacer wires welded at each end of the fuel rod by tungsten-arc inert gas spot weld

Zircaloy Welding Techniques Developed for Plutonium Recycle Program UO_2 Fuel Element Fabrication

involve six welding processes for fabricating nuclear fuel element components

BY L. E. MILLS

Hanford Laboratories is authorized by the Atomic Energy Commission to undertake the Plutonium Recycle Program (PRP) with the objective to develop technological basis for economical use of plutonium recycle in power reactor systems and demonstrate the recycle concept in a practical manner. The design and operation of the Plutonium Recycle Test Reactor (PRTR) is part of the program. A major portion of the initial fuel loading for the PRTR consists of Zircaloy clad natural uranium dioxide.

This paper discusses metal joining applications used to fabricate the uranium dioxide elements for the first PRTR loading. Zircaloy 2* is the only metal involved in assembly of these elements. Therefore, the physical properties of this alloy are all-important in selecting methods of welding. Table 1 lists several of the physical properties of Zircaloy 2 which directly affect weldability; the properties of 1010 cold-rolled steel are also listed for comparison.

The relatively low coefficient of thermal expansion of Zircaloy permits welding with little distortion and a low residual-stress buildup. Additionally,

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* Zircaloy 4 (Nickel 0.007%) was used for the later part of the program and differs from Zircaloy 2 (Nickel 0.07%) only in the nickel content. Decreased hydriding is realized with Zircaloy 4, however, other properties and weldability of the two alloys are identical.

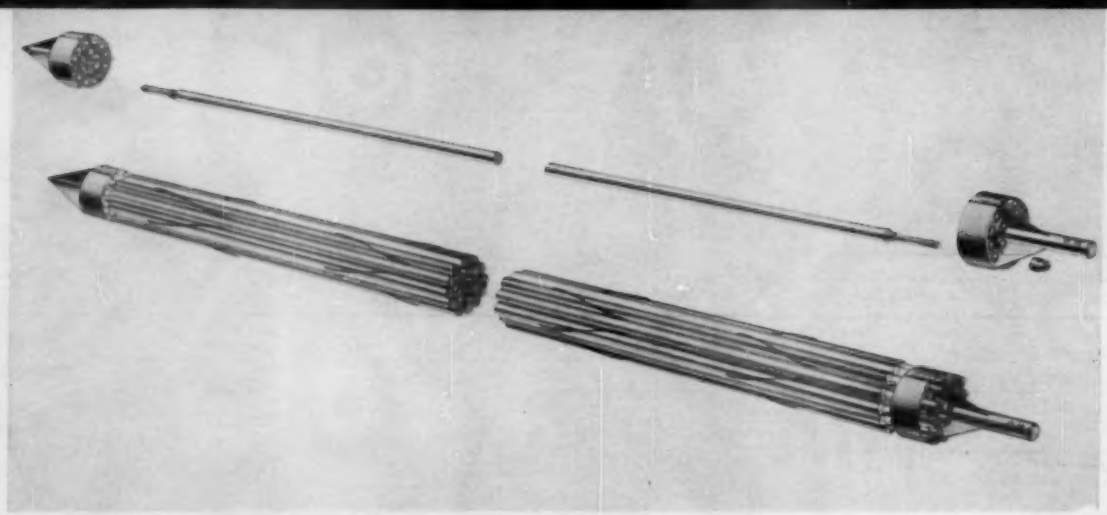


Fig. 1—19-rod cluster PRTR fuel element swaged UO_2 with Zircaloy 2 cladding

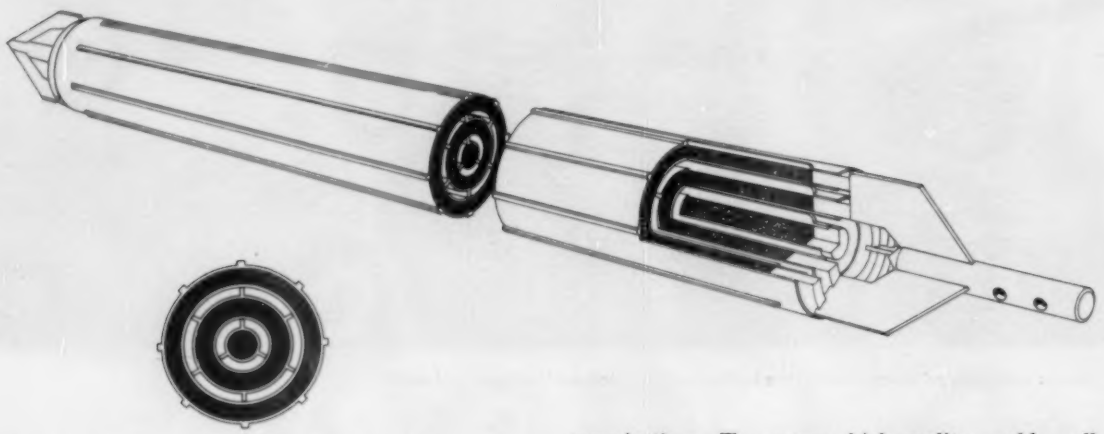


Fig. 2—Tubular ceramic fuel element assembly

the high electrical resistivity exhibited by Zircaloy makes it readily adaptable to resistance welding in addition to arc-welding techniques. The major problem encountered in welding this alloy is contamination of the heated metal by gases, notably oxygen and nitrogen. These impurities increase the hardness of the metal, lower the ductility and cause a loss of corrosion resistance. The production of ductile, corrosion resisting welds requires protection of the heated Zircaloy by a rigidly-controlled inert gas atmosphere or a vacuum, or by welding within a few milliseconds to prevent gas absorption.

Zirconium and its alloys are also sensitive to traces of chemical contaminants, particularly fluorides and perspiration. To assure high-quality welds, all Zircaloy joining areas must be carefully cleaned and handled with cotton gloves prior to welding. Weld areas are prepared by vapor blasting or machining to remove oxides and degreasing to remove oils and greases. The material is pickled for 30 sec in a nitric-hydrofluoric acid solution consisting of 3.7 vol % of 52% HF, 42 vol. % of 60% HNO_3, and 54.3 vol % of deionized H_2O. The freshly pickled Zircaloy must be dynamically rinsed to remove all traces of the pickling acids.

Table 1—Zircaloy 2 Properties Affecting Weldability

	Zircaloy 2	1010 steel
Thermal expansion, at 20° C	5.84×10^{-6} in./in./° C	12.2×10^{-6} in./in./° C
Thermal conductivity, at 20° C	0.028 Cal/cm²/-cm/° C/sec	0.140 Cal/cm²/-cm/° C/sec
Electrical resistivity, at 20° C	74×10^{-6} ohm-cm	14.2×10^{-6} ohm-cm
Melting point	1845 ± 25° C	1480 ± 20° C

The fuel elements for the first loading of the PRTR have a 3.25 in. diam and are 8.33 ft long. There are two distinct types of elements presently being fabricated: a 19-rod cluster element in Fig. 1 and a tubular element in Fig. 2. The majority of the elements fabricated for the PRTR have been 19-rod clusters.

There are six welding processes presently used in fabricating the above mentioned elements. These are arc- and resistance-welding techniques that have been developed to accommodate the properties of Zircaloy. The most widely used process is *inert gas tungsten arc welding*, performed within a closed chamber. An improved method *magnetic-force butt welding*, to make fuel rod closure welds and circumvent the use of an evacuated chamber, relies on a very short welding time to prevent gas

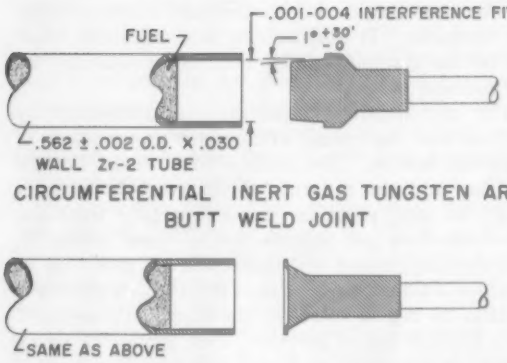


Fig. 3—Weld joint designs for fuel elements (top: circumferential inert-gas tungsten-arc butt weld joint; bottom: weld joint design for magnetic-force butt welding of PRTR fuel rods)

contamination. A *tungsten arc spot-welding* process is used to attach wire spacers to individual fuel rods. End hanger subassemblies for the cluster element are fabricated by *projection welding*. Ribs are welded to the tubular fuel element segments by a *450 kc resistance-welding* process that provides a continuous weld at a rate of 90 fpm. Finally, *resistance seam welding* is practiced as a part of a double closure technique for tubular fuel elements.

Fabricating the 19-rod Cluster Fuel Element

A total of 259 individual welds are required to fabricate a 19-rod cluster fuel element. Each cluster consists of 19 individual rods which are $^{9}/_{16}$ in. in diam and 7.83 ft in length. The fuel rods are clad with 0.030-in. thick Zircaloy 2. The Zircaloy cladding tube is filled with uranium dioxide powder and densified by swaging or resonance frequency vibrational compaction. During the swaging fabrication, a $^{3}/_{4}$-in. OD tube is filled, swaged to $^{9}/_{16}$-in. diam, cut to length and a closure cap welded on each end. In vibrational compaction, one end cap is welded to a $^{9}/_{16}$-in. diam tube of finished length, uranium dioxide is placed into the tube and compacted, and the resulting fuel rod is closed with a second end cap.

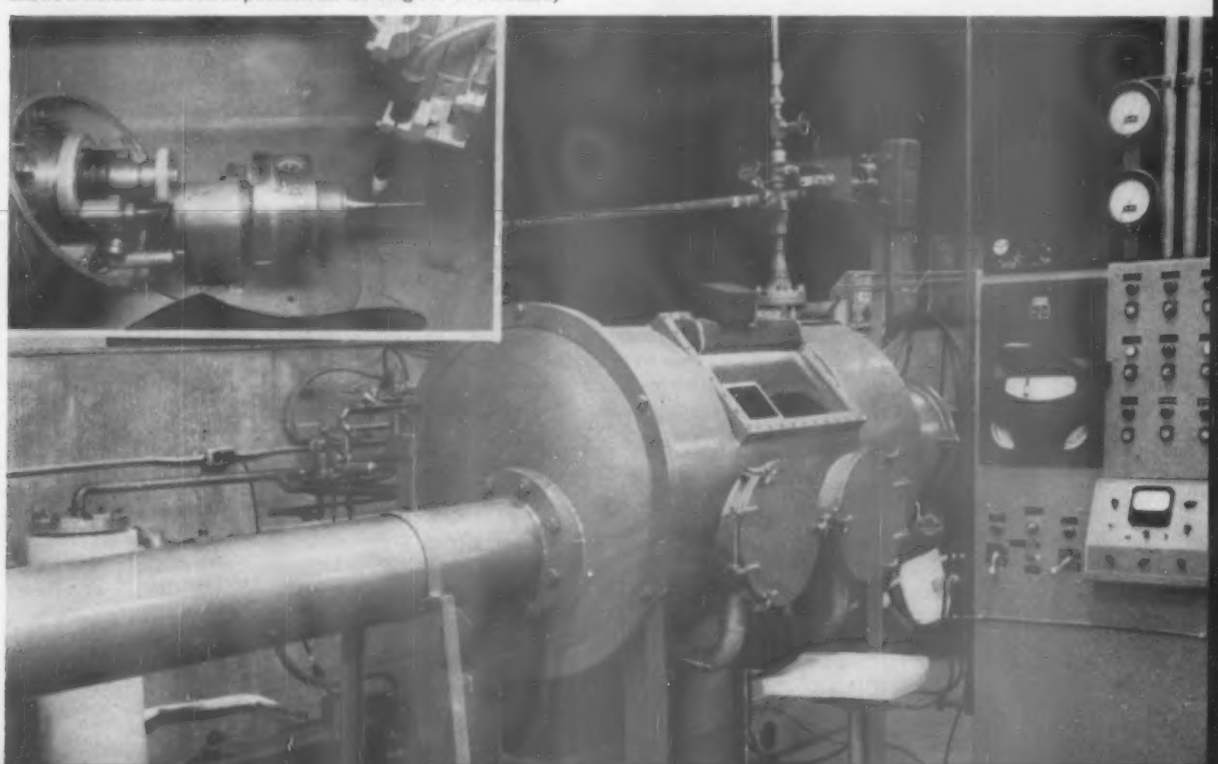
Each 19-rod cluster fuel element has twelve of the rods wrapped with a spacer wire to assure proper coolant flow through the element. End hangers are fabricated and the rods assembled with the hangers to form the 19-rod circular cluster configuration. An individual Zircaloy 2 wire is wrapped around the complete cluster to provide a tight fuel bundle.

Fuel Rod End Closure—Tungsten Arc Inert Gas Welding—Direct-current Straight Polarity

Two end cap weld joint designs, which have been perfected and will produce closures with a yield exceeding 99%, are illustrated in Fig. 3. The circumferential arc-weld joint is performed by the tungsten arc inert-gas process within a closed chamber. The second weld joint is used with the magnetic force butt welder and will be discussed in connection with that process.

For circumferential arc welding, the end caps are pressed into prepared fuel rods. An interference

Fig. 4—Vacuum-purged tungsten-arc inert gas welding chamber (Inset shows a welded fuel rod in position for welding the end closure)



fit of from 0.001 to 0.004 in. is required between the cap and the fuel rod. The portion of the cap that inserts into the fuel rod is machined with a continuous 1 deg taper to facilitate assembling the interference fit. The rods are placed in a 20-rod rotating jig, rolled into the welding chamber in Fig. 4 and evacuated to a maximum pressure of 3×10^{-4} mm of mercury. Subsequently, the welding chamber is backfilled with purified helium which has been dried and passed through an activated charcoal tower. A helium reservoir with 60 psi pressure is maintained between the purifying system and the welding chamber. This allows the 35-cu ft chamber to be backfilled in approximately 10 sec. Helium not only serves as the inert-gas welding atmosphere but also is required within the fuel rod for thermal conductivity during irradiation.

Originally, difficulty was encountered in attempting to strike an arc in the purified helium due to the inability to initiate helium gas ions. Tungsten inclusions could not be tolerated in the weld, thus ruling out a touch starting technique. A conventional high-frequency start procedure proved inconsistent. The high-frequency arc jumped from various points at the upper part of the electrode and did not provide sufficient helium ions at the tip of the electrode to initiate a welding arc. Various electrode shapes and sizes were explored with limited success. Finally, a quartz insulating sleeve was fused to the tungsten electrode $^1/_4$ in. above the electrode point. This sleeve forced the high-frequency arc to initiate at the end of the tungsten, ionizing the helium gas and permitting an effective welding arc. This technique has been very useful in starting low-current arcs as well.

Operation within the chamber is somewhat restricted. However, normal welding functions can be performed. The chamber is backfilled to atmospheric pressure, and the operator manipulates equipment by using long rubber gloves which extend into the chamber. A viewing window is provided to monitor the operation, with a welding glass moved into position when the arc is initiated. As the operator's working area is restricted, welding tools and materials must be kept within easy reach. These limitations have actually proved to be an asset; the operation must be performed as planned, and quality and consistency of welds have been correspondingly high.

The operator manipulating fuel rods within the chamber first pulls a rod from the fixture through a collet chuck where it is gripped, rotated and welded. When the weld is completed, the rod is removed from the chuck and returned to its original position. The jig is rotated to the next position and the sequence repeated with each fuel rod.

A continuous 8 cfh flow of helium is fed through the welding torch. The welding chamber is maintained between ±1 in. of water column pressure by a controller which operates an exhaust valve that is vented to a vacuum line. This system maintains a constant pressure during temperature buildup within the chamber. It also adjusts automatically while the rubber gloves are being inserted or retracted by the operator.

The arc length and position are optimized by vertical and horizontal micrometer adjustments of the torch holder. The torch is fixed at the 1100-hr position and the rod rotates clockwise beneath it. The fuel rod rotation is continuously indicated in revolutions per minute on a speed indicator. The welding current and time cycle are preset on an automatic timer; current start of 75 amp is provided. Within 30 deg of rotation, the current drops to 65 amp for 350 deg of rotation, then gradually slopes down to 15 amp and is extinguished. A dual channel Brush oscillograph provides a trace of the welding current and voltage amplitude with time and produces a trace which is typified by Fig. 5. Prior to closing each lot of fuel rods, the welding parameters are set up and checked. The speed indicator and oscillograph provide excellent control and assure a high-quality closure.

Each end cap that is circumferentially arc welded is provided with an outgas hole which serves a dual purpose. Air atmosphere within the fuel rod can be evacuated through this outgas hole, and the rod can be backfilled with helium to increase thermal conductivity during irradiation. This hole also provides an escape for gas expanded by heat generated during the weld. Without an outlet, the expanding gas would form a pocket beneath the weld metal at the termination point of the circumferential weld. The end of the fuel rod is cooled following the circumferential arc weld; subsequently, the outgas hole is closed by a quick manual tungsten-arc-welding operation.

Fuel Rod Closure—Magnetic Force Resistance Welding

Resistance butt welding is an economically attractive and preferred method of providing fuel rod closures. Fuel rod closures may be performed at a much faster rate with less operator skill, decreased volume of metal in the closure cap, a smaller amount of helium required for backfilling the fuel rod, and with an improved grain structure of hot-forged weld metal. Also, a protective atmosphere is not required for welding Zircaloy when the weld is performed in less than 20 msec; thus the operation may be performed in air as well as within any desired atmosphere. Resistance-welding processes use the heat produced by the electrical resistance of the parts to perform the weld. Zircaloy 2 has an electrical resistance of 74×10^{-6} ohm-cm at 70° F, which is five times that of low-carbon steel; therefore, it is readily adaptable to resistance-welding techniques.

Magnetic-force welding equipment differs from that of conventional upset-butt welding in that it provides an accurately controlled force increase during formation of the weld. With this excellent

control of welding force along with accurate control of the welding current and time, welds can be made in $^1/_{120}$ to $^1/_{60}$ sec. A highly responsive magnetic force is substituted for the conventional hydraulic or pneumatic force. The welding current is used to energize the magnet, producing an inherent synchronized relationship between the heat generation and pressure application.

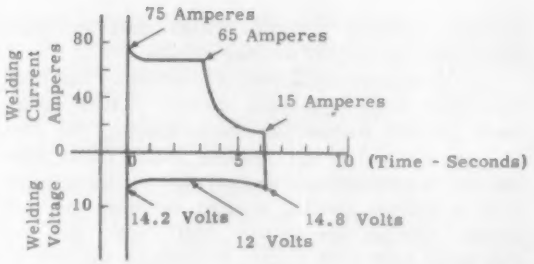
The magnetic-force butt welder used to close fuel rods at Hanford is shown in Fig. 6. An individual rod is extended 0.035 in. through a collet electrode and secured. The fuel rod cap is inserted into a cavity in the moving electrode. A 75-cu. in. evacuable chamber surrounds the electrodes and weld area providing a means of welding within any desired atmosphere. An initial force of 500 lb is applied as the parts are brought together. The welding current follows a path from the welding transformer to a one-turn copper loop, through flexible copper straps to the moving electrode, into the fuel rod cap, across the joint between the cap and rod cladding, through the collet electrode and back to the transformer. In this path the point of high electrical resistance is at the interface between the cap and fuel rod where the necessary heat is produced to form the weld. There is no arcing between parts; heat is generated entirely by electrical resistance of the metal.

The welding current creates a strong magnetic field about the iron core located within the one-turn copper loop in the welding circuit, which in turn attracts a steel armature attached to the moving electrode. Thus, as the welding current builds up during the first $^1/_{120}$ sec, the force holding the parts together also increases in absolute synchronization. The relation of the armature to the iron core can be adjusted mechanically to vary the welding force and permit some adjustment in time of the force increase.

Welds made to study the various parameters involved in perfecting a cap design resulted in recommendation of the joint shown in Fig. 2. The closure cap must have a metal cross section approximately equal to that of the cladding at the weld joint to achieve the proper heat balance between the rod and the cap. The following weld sequence produced an excellent closure on $^9/_{16}$-in. OD, 0.030-in. thick Zircaloy 2 clad tubes in helium atmosphere. Slightly less welding current is required when making the closure weld in air or within a vacuum because the lower thermal conductivity of the surrounding media.

Welding current:
20,000 amp for first $^1/_{120}$ sec;
24,000 amp for final $^1/_{120}$ sec
Total weld time: $^1/_{60}$ sec
Initial preweld force: 500 lb
Magnetic gap: $^{11}/_{16}$ in.

A conventional 60 cycle per sec single-phase power supply is utilized with a special synchronous welding



Current and Voltage for Welding Zircaloy-2 Clad UO_2 Swaged PRTR Fuel Elements

Fig. 5—Typical oscillograph trace of welding current and voltage at a chart speed of 5 mm per second

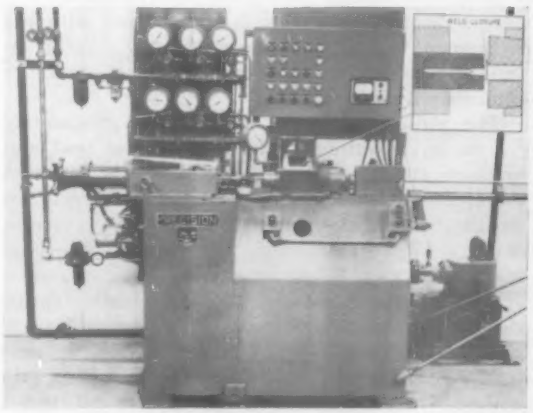


Fig. 6—Magnetic-force butt welding machine

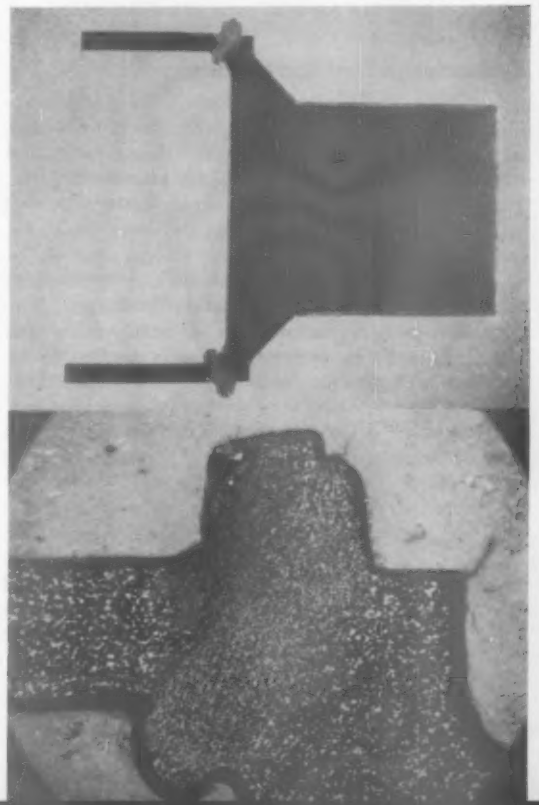


Fig. 7—Fuel rod closure weld made by magnetic-force butt welding—Zircaloy 2 material (macro-photograph at top at × 7 magnification, micro-photograph at bottom at × 50 magnification—both reduced approximately 50% upon reproduction)

control providing accurate phase shift for each individual half cycle of welding current.

This extremely rapid welding operation has been monitored with high-speed motion picture equipment (16,000 frames per sec). During the first $^1/_{120}$ sec, the end of the cladding heated faster than the cap and upset back against the collet electrode, with a definite cooling noticed between the half cycles. During the second half cycle, the cap and upset tube heat evenly to produce the desired weld. The weld metal upsets both internally and externally as the weld area shortens during the operation. The high-speed film revealed a distinctly separate metal movement during each half cycle, emphasizing the need for the highly responsive magnetic-force and a low inertia moving electrode. Figure 7 illustrates a typical weld contour. A narrow heat-affected zone is encountered with the weld metal exhibiting a fine hot forged, grain structure in contrast to the large grain cast structure common with arc welding.

The rod assembly is shortened approximately $^1/_{32}$ in. by upsetting of the metal under heat and pressure at the weld area. While external upset metal must be removed by a subsequent shearing or machining operation, the internal upset provides a transitional cross-section increase from the thin-wall fuel rod cladding to the thicker cap.

Magnetic-force welding produces high-integrity closures on rod type elements in $^1/_{60}$ sec without a protective atmosphere. Normal operating procedure permits 250 resistance butt welds to be made in 1 hr. Sixty closures per hour may be performed with the evacuation and backfill sequence providing any desired atmosphere prior to making the closure.

The as-welded appearance of typical circumferential tungsten arc and magnetic-force resistance welds are shown in Fig. 8.

Evaluation of Fuel Rod Closures

Rigid quality control and inspection systems are maintained to assure high-integrity fuel rod closures. The accurately predetermined welding schedules are most helpful in providing very reliable closures. However, in addition, each weld undergoes five separate checks during the fuel rod inspection program.

The fuel rod has an internal helium atmosphere and the first inspection is a helium leak test. The complete rod is enclosed in a small evacuated chamber, and a mass spectrometer is used to detect possible helium leakage in either the cladding or weld.

Each weld is radiographed in four positions to show a cross section at 45 deg intervals about its circumference. These radiographs provided very essential information necessary to evaluate the quality of the arc welds. Radiographs of resistance butt welds are much more difficult to interpret, and an ultrasonic scanning method is being investigated to evaluate these welds. Accurate monitoring of the operating current and voltage drop across the weld area will determine the acceptability of the resulting weld; it will also serve as a nondestructive test for resistance butt welds.

The complete fuel rod is examined for defects utilizing a fluorescent, zyglo penetrant dye inspection. The performance of an autoclave corrosion test (450° C, 1150 psi steam for 72 hr) must produce a glossy, black oxide film to insure adequate corrosion resistance. Any trace of a white oxide autoclave film is cause for immediate rejection.

Finally, prior to assembling the fuel cluster, a close visual inspection of each rod checks physical dimensions and assures freedom from pits or inclusions. Periodic metallographic examinations are performed to supplement the above inspection methods.

Spacer Wire Attachment—Tungsten-arc Spot Welding

The fuel rods are properly spaced in the fuel bundle by wire spacers wrapped spirally about 12 individual fuel rods in each fuel element. The wire spacer is attached to each end of the fuel rod by tungsten-arc inert-gas spot welding. Both the rod and wire are autoclave tested prior to assembly and exhibit a normal black oxide film which does not interfere with the performance of the weld. One end of the spacer wire is inserted through a hole in the end cap and allowed to extend $^1/_{16}$ in. beyond it. A conventional tungsten-arc spot-welding gun equipped with a properly formed quartz nozzle is placed over the end of the extended spacer wire to perform the weld as shown in the lead photograph. An 8 sec argon purge and a 10 sec post-flow provide the necessary atmosphere shielding for a $^1/_4$ sec arc spot weld. A satisfactory weld is indicated by shiny, silver weld metal closing the hole in the end cap. The spacer wire is then mechanically wrapped about the rod at a 10-in. pitch and inserted through a similar hole in the opposite end cap. A second arc spot weld is made at this end of the spacer to maintain proper tension between the wire and the rod.

End Hanger Subassembly

The Zircaloy 2 hanger hardware shown in Fig. 9 is fabricated from 24 pieces of rod, sheet and tubing. The welded fabrication proved to be more economical than other machined and cast designs which were investigated. Subassemblies are fabricated by either inert-gas tungsten-arc plug welding or projection welding. The newer projection-welding technique eliminates the drilling and countersinking of holes required with plug welding and eliminates the post-weld machining operation.

Projection Welding

To effectively weld the hanger locating sleeves to their support ring, a projection shape for $^1/_{16}$-in. thick Zircaloy 2 was developed. The projection punch recommended by the Resistance Welding Manufacturing Association for steel, shears the

projection into the Zircaloy and produces a crack at the crown of the projection. To achieve the desired projection, a truncated cone punch having a flat end diameter one and one-half times as thick as the material was perfected. This punch was machined to form a 90 deg included angle. In contrast to the conventional punch, which stretches metal, this punch gathers the material into the projection. The metal must be coined into a die to assure consistent projection height and shape. A spherical projection button provides the strength necessary to support the electrode force during the weld formation.

Figure 10 illustrates the projection and weld cross sections. Three projection welds are performed simultaneously in $^1/_{30}$ sec, which is sufficiently short to eliminate the need for complete inert-atmosphere protection. If the weld time is longer, the Zircaloy will gather oxygen and nitrogen from the atmosphere and produce welds with unsatisfactory corrosion resistance. A low-inertia system is required to force the electrodes to follow the collapsing projection and prevent expulsion of weld metal. A spring-loaded electrode holder provides this movement during the short ($^1/_{30}$ sec) weld time. Figure 11 shows this holder, the fixture for positioning subassemblies, and also the appearance of the parts prior to welding. Each locating sleeve is 0.355-in. OD, $^1/_{16}$-in. thick and is attached by three projection welds formed in the support ring. A copper pin is inserted in the sleeve prior to welding to prevent its collapse. The sleeve rests in a cradle-like lower electrode and the support ring is held in position above it. The ring is contacted by an electrode shaped to match its contour. A partial atmosphere protection consisting of an argon-flood shield along the parts interface will minimize gas contamination during the weld. The projection welding technique has reduced over-all machining and labor costs to approximately 50% of those for plug welding.

Tungsten-arc Inert-gas Plug Welding

An alternate method of fabricating the sub-assemblies by plug welding may be used where projection welding equipment is not available. The support ring must be drilled with $^1/_8$-in. diam holes and countersunk to accommodate weld penetration into the locating sleeves. The sub-assemblies are held in a stainless steel jig where the sleeves are tack welded to the rings. Outgassing of the jig is a constant problem when Zircaloy is being welded, and the parts must be removed from the jig for finish welding. The plug welding must be performed within a closed welding chamber to prevent gas contamination.

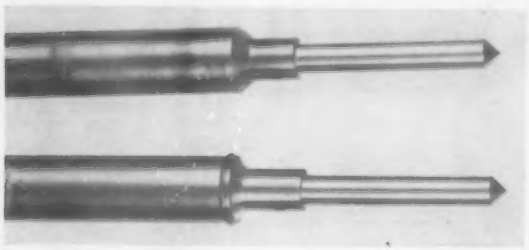


Fig. 8—Fuel rod closure welds (tungsten-arc inert gas weld at top; magnetic-force butt weld at bottom)

Fig. 10—(Top) Zircaloy 2 projection cross-section in $^1/_{16}$-in. thick material, × 13 magnification; (bottom) PRTR 19-rod hanger subassembly projection weld cross-section, × 10 magnification—both reduced 50% upon reproduction

Fig. 9—19-rod cluster fuel element hanger fitting assemblies and components—Zircaloy 2 material

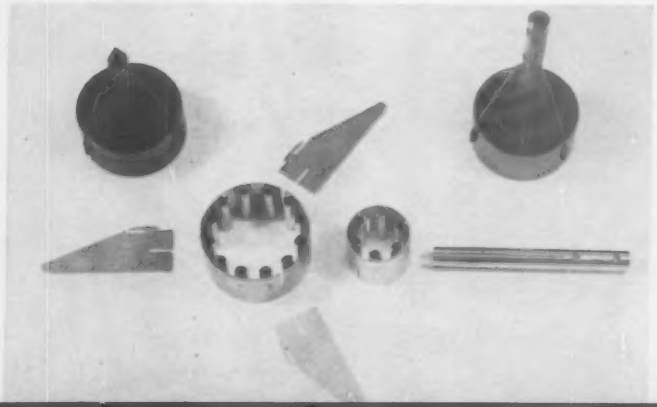
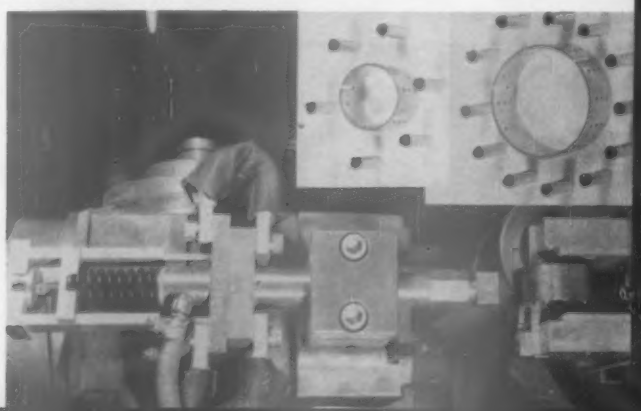


Fig. 11—Projection welding fixture for welding Zircaloy 2 hanger sub-assemblies



End Hanger Assembly—Tungsten Arc Inert Gas Welding

Final assembly of the hanger hardware is accomplished by tungsten-arc welding within the evacuated and backfilled chamber. A simplified hanger design provides self-location of the parts during final assembly. Three support fins are fillet welded to the center post using reactor-grade Zircaloy 2 wire filler material. The two support rings are positioned concentrically about this center post in the final assembly. The smaller ring, with six locating sleeves attached, is assembled first and welded to the three support fins. Subsequently, the larger support ring, containing twelve locating sleeves, is oriented about the small ring and welded to the fins. The assembly is visually inspected and autoclave tested before being incorporated in a PRTR fuel element.

Fuel Element Assembly

The 19-rod cluster is mechanically assembled to form a compact fuel bundle. The center rod is pinned to the top hanger center post, while the other rods are positioned by their locating sleeves. Each rod except the center one, is attached to the top hanger by slipping its threaded end cap through the locating sleeve and securing it from above with a nut. The lower hanger is oriented beneath the rods which are positioned in their respective sleeves; once aligned, the hanger is pinned to the center rod. This pin is tungsten-arc inert-gas spot welded to the hanger to secure the bundle. Finally, a wire is wrapped about the entire bundle and tungsten-arc inert-gas spot welded at either end of the assembly.

Fabricating the PRTR Tubular Fuel Element

The tubular fuel element is comprised of three concentric Zircaloy 2 clad fuel segments as illustrated in Fig. 2. The center segment is a solid rod and is surrounded by two tubular fuel segments with progressively larger diameters. The cladding about all fuel sections is Zircaloy 2 of uniform $^1/_{16}$-in. thickness. The diameters of individual fuel segments of the Mark II-C design are as follows:

	ID, (in.)	OD, (in.)
Central fuel rod	...	0.668
Inner fuel tube	0.962	1.902
Outer fuel tube	2.208	3.068

Coolant must flow between the fuel segments to maintain satisfactory in-reactor temperatures. Therefore, ribs are continuously welded along the center rod and outer cladding of both fuel tube segments. These ribs serve to space the fuel segments and orient the element in the reactor fuel tube. Initially, an integral rib and tube extrusion was explored. However, the cost of extruding the ribbed tube was prohibitive.

After the ribs are attached, one end of each fuel segment is closed. The center segment is a rod and is welded in the same manner as those in the cluster element. The inner and outer fuel tubes are resistance seam welded and tungsten arc inert gas circumferential welded for double assurance of a reliable closure. Subsequently, the fuel segments are loaded with granular uranium dioxide and vibratorily compacted to the required high density. After performing a second end closure, the three sections are nested and hanger assemblies secured.

Rib Spacer Attachment—450-kc Resistance Welding Machine

A special high-frequency resistance welding machine facilitates continuous joining of spacer ribs to

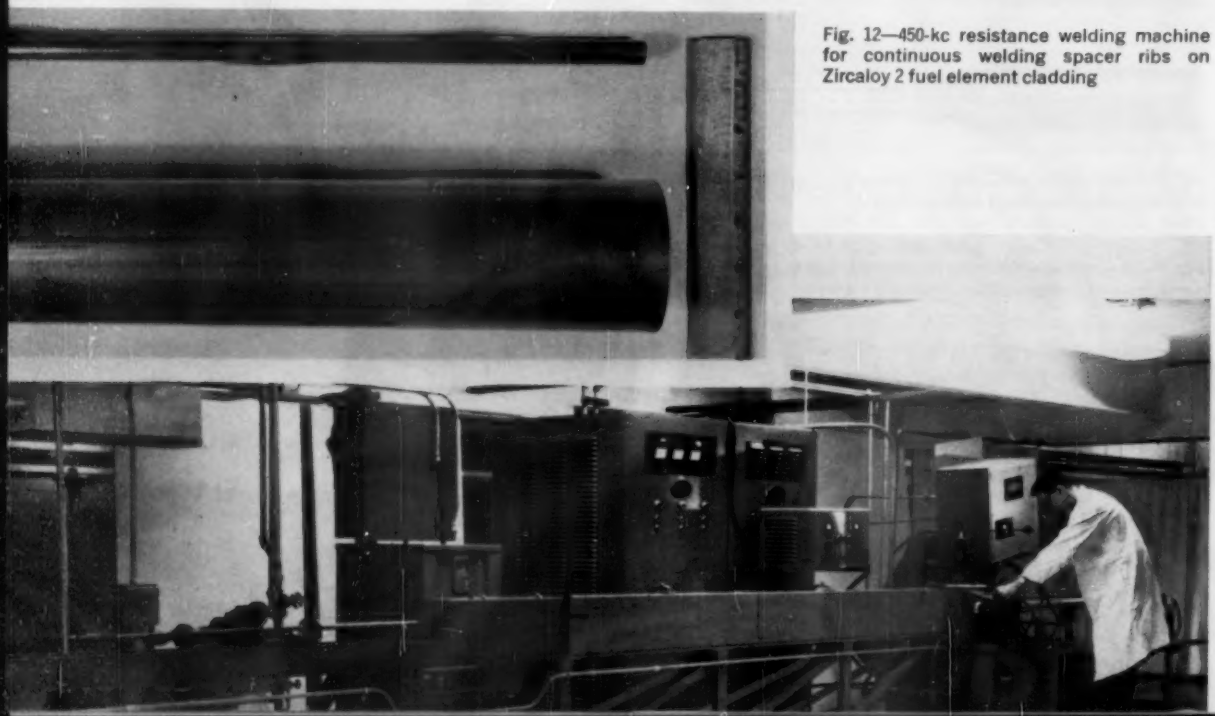


Fig. 12—450-kc resistance welding machine for continuous welding spacer ribs on Zircaloy 2 fuel element cladding

tubing. This unit will weld straight ribs on tubes up to 9 ft long at a speed of 90 fpm. To meet design requirements for the tubular fuel element, three ribs are welded to the center rod, six ribs to the inner fuel segment, and eight ribs to the outer segment. A continuous weld is performed by the 450 kc resistance welding machine pictured in Fig. 12.

The ribs are individually welded to 8 ft lengths of Zircaloy 2 tubing. The tube and rib stock are pulled through the welding mill with a draw bench arrangement. As the rib approaches the tube, it forms a vee with an included angle of seven degrees. A pressure roller presses the rib and tube together at the apex of the vee and the weld is formed. An internal mandrel is provided for tube support under the pressure roll. The 450,000 cps welding current is introduced to the rib and tube by sliding electrical contacts about $1^1/_4$ in. from the apex of the vee. The current flows from the sliding contact on the tube, through the tube to the point of rib contact, and back along the rib to the second sliding contact—schematically illustrated in Fig. 13.

This high-frequency current exhibits a "narcissism" which causes the current in the two legs of the vee to seek proximity. The current and generated heat concentrate at the lower edge of the rib and on the tube surface immediately beneath the approaching rib. Unlike induction heating, this process relies on the material's resistance to the flow of the supplied current for heat generation. A 60 kw power supply provides the required welding current. The amplitude of the current is controlled mechanically by changing the position of a ceramic reactance plug in the secondary loop of the welding transformer.

To protect the heated Zircaloy from contamination, an argon gas shield is provided around the heated tube and rib. A porous metal gas diffuser is used in the weld area and extends for 8 in. along the path of the hot material. As the work emerges from the short diffuser chamber, jets of rapidly expanding argon gas assist in cooling the material.

The specified rib is a rectangular shape 0.075 in. in width and the height to be 0.078 in. on the large fuel segment, 0.143 in. on the middle fuel segment, and 0.137 in. on the center fuel rod. A sliding electrical contact was initially provided on the side of the rib and resulted in nonuniform current distribution across the welding face. A more uniform current distribution was obtained by contacting the top edge of the rib. The rib cross section did not permit the flow of sufficient welding current to perform a full width 0.075-in. weld. Therefore, the corners of the rib were removed to form a rib and tube contact width of 0.020 in. This 0.020-in. weld width provided sufficient strength for spacer rib attachment. Attempts to join ribs with a height of less than 0.135 in. to the tubing resulted in the rib overheating before the tube reached the welding temperature. As the outer tube required 0.078-in. high spacers, ribs of 0.135-in. height were welded in place and the excess removed by subsequent machining.

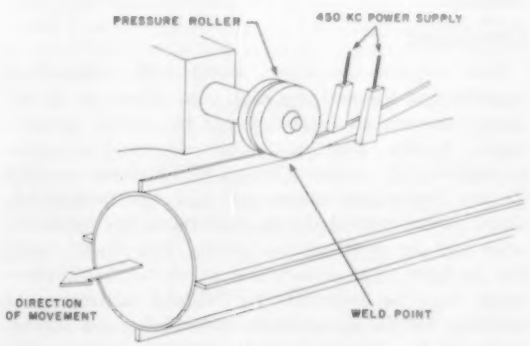


Fig. 13—Joining fins to a tube by 450-kc resistance welding

A wide range of weld strength is possible using this machine. Low power operation produces welds that barely tack the rib to the tube—welds that can easily be broken by twisting with pliers. As power is increased, the weld becomes correspondingly stronger. However, as weld strength increases, greater amounts of beaded upset material are forced out of the weld area at the base of the rib. Again, high-speed motion picture equipment was used to detect the cause of this bead expulsion. The film, operating from 2000 to 16,000 frames per sec, indicated short, intermittent arcs in the vee notch before the parts make contact. This arcing was responsible for the formation of beads at the base of the rib. The tendency to arc has been reduced, although not eliminated, by using a 7 deg included angle for the approaching parts.

Initially, the use of sliding electrical contacts resulted in galling the Zircaloy surfaces. A silver 5% graphite electrode partially resolved this problem. However, much of the galling proved to be a result of intermittent arcing between the contact and workpiece. Although a liquid pool surrounding the contact area would reduce the arcing, the solution would introduce an undesirable Zircaloy contaminant. Originally, only the toe of the electrical contact touched the work, forming a vee notch between the electrodes and the work, which abetted arcing and resulted in undesirable heating at the electrode. Rolling contacts were investigated and found unsatisfactory. The natural approach angle between the roller and work produced a vee which is conducive to arcing. Small sliding electrodes providing a full width contact resulted in the least amount of galling.

The position of the sliding electrical contact may be shifted on the work to assist the heat balance problem. Placing the contact on the rib close to the weld point and the contact on the tube farther from it will provide a short welding current path in the rib and a long current path in the tube. Thus, a larger amount of energy is dissipated in the tube than in the rib.

Distortion of the tube during welding has been a

serious problem. Each time a metal tube is heated on one side it will distort. Eight ribs cannot be welded to the large tube by progressing around the tube in 45 deg increments. Rather, ribs must be welded in a sequence of 180 deg increments. When rib nos. 1, 5, 3, 7, 2, 6, 4 and 8 are welded in this order, the tube will remain essentially straight. There will be small amount of cloverleafing between ribs. However, this is within the specified fuel element tolerance. The distortion is more pronounced when three ribs are welded to the center fuel segment cladding. This rod must be straightened prior to loading it with fuel.

The 450 kc resistance welder may be used to weld a spiral wire continuously to a tube. Eventually, this spiral weld may replace the mechanical wire wrap for individual rods of the cluster element. Again, the major problem encountered is that of proper heat balance between the rib and the tube. The rib cross section must be large enough to accommodate the necessary welding current.

Although welds of sufficient strength may be produced with this process, occasional unsatisfactory corrosion resistant weld areas are encountered. Three conditions which contibute to the corrosion area are: inability to rinse the etching solution from a crevice between the wire and the tube, occasional atmosphere contamination, and electrode material transfer to the work.

Tubular Fuel Segment End Closure

A closure is made on one end of the tubular fuel segment prior to loading the fuel. After loading, the same operation is performed on the second end. Closure of the individual rod in a cluster has been discussed, and the same procedure is used for the center rod fuel segment of the tubular element. Two welding techniques are employed to provide a double weld closure on each end of the inner and outer tubular segment.

Resistance Seam Welding

The initial closure for the fuel tubes is accomplished by resistance seam welding. A solid Zircaloy 2 end ring is inserted between the inner and outer cladding of the fuel segment. The end of the tubular segment is placed over a small rotating seam-welding wheel, which has a diameter approximately $^1/_8$-in. smaller than the segment's inside diameter. This wheel contacts the inside cladding while a wheel of 18-in. diam contacts the outer cladding. Figure 14 shows the seam welding operation in progress. Each pulse of weld current passes through the inner cladding, the plug and the outer cladding. The high electrical resistance at the interface between both the inner and outer cladding and the plug generate a weld at each point. Thus, two welds are produced simultaneously as the weld current pulses intermittently through the work. Between each pulse, the seam welding wheels are rotated to provide a new joint position. Each intermittent weld overlaps the previous weld by approximately 50% and progressively forms a continuous weld around the periphery of the tubular fuel segment. Each weld current pulse is $^1/_{12}$ sec in length. A relatively long (2 sec) cooling time is provided between pulses allowing the water cooled copper wheels to remove heat from the work. This is required to prevent exposed Zircaloy from attaining a temperature conducive to gettering oxygen and nitrogen from the air. Inert gas shielding is not provided for the seam welding operation. A three-phase frequency converter power supply controls the welding current for the seam welding.

Tungsten Arc Inert Gas Welding

The final step in the double closure is to insert the tubular fuel segment in the vacuum-purged chamber and tungsten arc inert gas weld the closure ring to both the inner and outer cladding. The finished appearance of the double closure is illustrated by the inset of Fig. 14. Procedures within the chamber are essentially those discussed previously for tungsten arc insert gas welding for fuel rod closures.

Upon completion of a double closure on one end of the fuel segment, it is filled with uranium dioxide power and vibratorily compacted to the required high density. An end ring is inserted between the inner and outer cladding at the open end of the segment and the double closure procedure is repeated. Since thermal conductivity requires a helium atmosphere within the fuel segment, two outgas holes are provided in the second plug ring. These outgas holes are welded closed within the vacuum purged chamber.

End Hanger Attachment— Tungsten Arc Inert Gas Welding

After the three concentric fuel sections have been completed, the center rod is nested within the inner fuel segment. This in turn is nested within the outer fuel tube; each segment is spaced by the Zircaloy ribs. The entire assembly is placed into the vacuum-purged chamber for end hanger attachment. Each hanger is comprised of a center post and three fins. The fins extend radially from the center post to the outer tube and are permanently attached to the ends of the fuel tubes by tungsten arc inert gas welding.

Conclusion

Safe reactor operation, along with radioactive hazards and the extreme high cost of reactor downtime demands all fuel elements to exhibit high-integrity welds. Zircaloy 2, the only cladding material used in fabrication of initial PRTR elements, with its low-thermal expansion and high-electrical resistance, is readily welded with high reliability by resistance and arc welding processes. The major welding problem—gas absorption at elevated temperatures—can be overcome by faithful adherence to welding within a carefully controlled inert atmosphere or by completing the weld in a few milliseconds. Zircaloy must be carefully cleaned and

Fig. 14—Resistance seam welding the closure plug on a tubular fuel element segment (Inset shows appearance of finished double closure, including resistance seam weld and tungsten-arc inert gas weld)

protected throughout fabrication to prevent contamination of welds by foreign materials. Tungsten arc inert gas welding has been used extensively with the Zircaloy properly protected by rigidly controlled inert atmosphere. In addition, butt, projection, seam, and 450 kc resistance welding processes have been utilized, with less rigorous atmosphere protection requirements.

The assurance of high-quality welds requires accurately pre-established welding parameters. During the fabrication of nuclear fuel elements, continuous instrumentation and rigid quality control procedures are practiced. It is this adherence to standards and procedures, together with proper equipment, that will assure high-quality welds.

Acknowledgment

The author expresses his appreciation to the many people assisting in preparing this report. J. Scherger and R. F. Boolen prepared the Zircaloy and performed the welding operations of the many test samples in addition to making the welds required to fabricate the fuel elements; E. H. O'Claire performed the numerous nondestructive evaluations; L. A. Hartcorn prepared the metallographic specimens; J. L. Hascall provided the photography and J. A. Moir the technical editing.

Bibliography

1. Lustman, B., and Kerge, F., Jr., "Metallurgy of Zirconium," Div. VII, Vol. 4, National Nuclear Energy Series, McGraw-Hill Publishing Co., New York, N. Y. (1955).

2. Vagi, J. J., and Martin, D. C., "Development of Methods for End Capping PWR Fuel Elements," THE WELDING JOURNAL, 37, (11), Research Suppl., 499-s to 506-s (1958).

3. Aungst, R. C., "Development of Ribbed Jacket Tubing for PRTR," Hanford Atomic Products Operation Document No. HW-61797.

4. Mills, L. E., "Magnetic-Force Resistance Butt Welding of Zircaloy 2 Fuel Element Closures," Hanford Atomic Products Operation Document No. HW-62482.

5. Millhollen, M. K., "Specifications for Swaged UO_2 19-Rod Cluster PRTR Fuel Element, Mark I," Hanford Atomic Products Operation Document No. HW-64359.

6. Richards, E. L., and Hurford, W. J., "The PWR Fuel Element End Closure Development Program," AEC Research and Development Report WAPD-MDM-9.

Practical Welder and Designer

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Based on a story from the Air Reduction Sales Co., New York, N. Y.

Fig. 1—40-ton capacity all-welded aluminum bottom dump trailer built for hauling asbestos at Asbestos Corp.

Fig. 2—Here the final "deck" plates are being welded into position with a "pull" gun; the longitudinal welds and all tack welds account for approximately 70 lb of welding wire being used in each unit

This unique truck fabrication by Atlas was the result of the opening of the new King-Beaver asbestos ore processing mill at Asbestos Corp. Limited's location at Thetford Mines, Quebec. The task of transporting material $1^1/_2$ miles between the ore crushing plant at Old King mill site and the new processing mill was studied by the corporation, Atlas, and the material supplier, Aluminum Co. of Canada, Ltd.

It was decided that three rear dump trucks with 27-ton-per-trip capability would be required to meet the new mill's demand of moving 200-tph of crushed ore 24 hr per day. However, this proved too high for a profitable hauling operation, since a capital outlay of $150,000 would be needed excluding estimated operating costs.

To maintain an economical movement of ore over the short haul distance, a payload of 40 tons was considered essential. A steel body in excess of 28,000 would be needed to carry the load. This deadweight combined with the crushed ore, demanded use of a heavy traction unit which the company wanted to avoid. It was concluded that an aluminum botton-dump trailer would be needed to transport the load with a standard highway tractor. However, no existing truck builder manufactured such a carrier unit.

Following a discussion with the asbestos firm, Atlas hit upon a suitable design—Fig. 1. Atlas, a pioneer in designing and constructing steel and alloy bodies, developed the carriers from high strength $^1/_4$- to $^3/_8$-in. thick 54S Alcan aluminum plate. Total unit weight amounted to only 15,000 lb, some 13,000 lb lighter than an equivalent steel body. Two bottom dump units enabled Ford 275 horsepower Model F-1100 tractors to make the complete circuit in 10 min, 35 sec, carrying 40 ton loads up a 2% grade.

Fabrication was carried out at Atlas' Montreal shop using the gas-shielded metal-arc welding process. Two manual guns were used on the assembly line. A welding gun with push-type wire feed was used for the initial tack welds. These

welds were made with $^3/_{64}$-in. diam 56S aluminum wire at the rate of 350 to 375 ipm.

Work in this stage of the dump body floor assembly was positioned so that most of the welds were in the flat or horizontal fillets. Welding of sides and ends of each body, or general out-of-position work, was done with a "pull" gun, using $^1/_{16}$-in. diam 56S aluminum wire at speeds of 255 ipm—Fig. 2. Pure argon shielding gas was used in both units with flows of 45 to 50 cfh.

The welding process described here was selected by Atlas because it not only fitted the needs of aluminum fabricating but was adaptable to mild steel and stainless steel welding as well. Combined total costs for the two dump units approximated $65,000, a saving of $85,000 on the equivalent steel body models. A reduction of $68,000 gross is expected annually on operating expenses. Further economies are foreseen in faster turn rounds resulting from the bottom dumping feature and reduced deadweights. Easy maintenance on tractors is also expected since local dealers stock spare parts.

As one of Canada's leading manufacturers of heavy duty haulage equipment, Atlas is now forging ahead in the fabrication of aluminum bodies. The firm manufactures 15 cu yd dump bodies measuring 14 ft 6 in. long and 7 ft wide, and 52 in. high. The approximate weight of these units is about 4200 lb lighter than steel-body units. Twenty-four and nineteen cubic yard mining dump model trucks are also under construction with weight savings up to 50% over comparable steel models. These bodies are being produced for replacement of new and original equipment.

Karting Is Contagious

Let's go "karting!" This new family fad which began in California only two years ago has resulted in a contagion of ardent kart fans and owners all across the country.

What is "karting?" It is the sport of whizzing along just 2 in. above the ground at speeds from 35 to 60 mph, plus. The thrill comes from the small size of the sled-like kart, its ground-hugging profile and its uncanny cornering ability, all of which serve to magnify the already blurring speeds. A former sports car racer has compared the thrill of "karting" to driving a Big Five car in the 500-mile Indianapolis race.

One of the leading kart manufacturers is Mercury Tool and Machine Service, Waco, Tex. Mercury's "Hornet" line of karts range from driveway models for the kids to high-speed racers for the kart enthusiast. All utilize a 0.062-in. thick-wall tubular steel frame, jig-assembled with short-arc gas-shielded consumable-electrode welding equipment.

Type 1020 steel tubing is cut to length, coped and bent to form the frame components. These are then clamped in a jig and fillet-welded using a torch operating at 90 amp, 18 v and utilizing 0.030-in. diam steel 65 wire. Slope-controlled cp power is used, and shielding gas is an argon-carbon dioxide mixture.

Short-arc welding employs precisely-controlled, low-voltage pinpoint-arcs shielded by the argon-CO_2 gas mixture. Shorting the arc lets the puddle cool, minimizing heat distortion and controlling burnthrough for ideal penetration.

Previously, Mercury had used covered electrode welding on this assembly. However, weld porosity occurred, resulting in poor appearance. In addition, slag removal after welding slowed production. Two men were able to reduce only 10 frames a day at a cost of $7.50 per unit. Now with short arc welding's high speed, semiautomatic operation, and spatter-free welds, weld appearance has improved, no post-weld finishing is required, and two men can produce 20 frames a day at only $4.00 per unit.

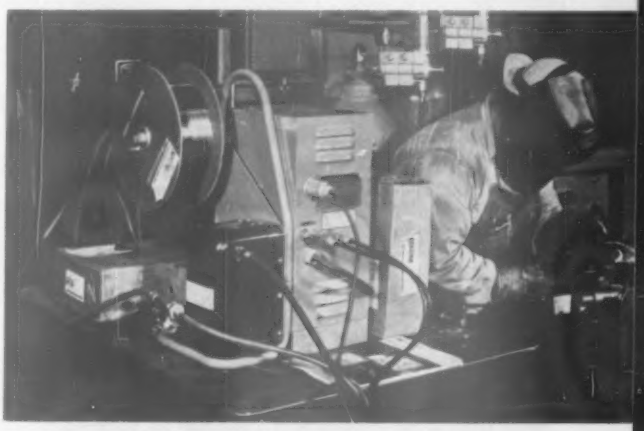


Fig. 1— Short-arc welding of kart frames doubled production at Mercury Tool & Machine Service, Waco, Texas; porosity and post-weld cleaning were eliminated

Fig. 2—With finished "Hornet" kart in foreground, operator welds kart frame held in specially-designed jig

Based on a story from the Linde Co., New York, N. Y.

UNITED ENGINEERING CENTER

Steady progress in the construction of the United Engineering Center is shown in this picture taken from the United Nations Plaza. The Center is to be the new home of AWS

See for Yourself in April

Construction of the new United Engineering Center in New York continues to proceed at a steady pace in order that occupancy in mid-1961 will be assured.

AMERICAN WELDING SOCIETY members who plan to attend the 42nd Annual Meeting and Exposition in April are invited to venture to the United Nations Plaza on Manhattan's East Side to see firsthand what their pledges are helping to build. The AWS will be headquartered on the 8th floor.

Several new sections appear on the Honor Roll for having achieved 100% or better of their goal. However, AMERICAN WELDING SOCIETY pledges stand at 63% of goal.

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	125	Long Beach	100
Mahoning Valley	113	Louisville	100
Hartford	104	Maryland	100
Kansas City	102	Nashville	100
N. E. Tennessee	102	New Hampshire	100
Puget Sound	102	New Jersey	100
Tulsa	102	N. Central Ohio	100
Baton Rouge	101	North Texas	100
Colorado	101	Northern N. Y.	100
Detroit	101	Olean-Bradford	100
Niagara Frontier	101	Pascagoula	100
Providence	101	Philadelphia	100
Rochester	101	Salt Lake City	100
St. Louis	101	Richmond	100
Birmingham	100	San Antonio	100
Boston	100	Sangamon Valley	100
Bridgeport	100	Santa Clara Valley	100
Chattanooga	100	Syracuse	100
Cincinnati	100	Toledo	100
Dayton	100	Western Mass.	100
Eastern Illinois	100	Wichita	100
Holston Valley	100	Worcester	100

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Mohawk Valley	100	Madison-Beloit	400
Tri-Cities	100	Western Michigan	400
Albuquerque	150	York-Central Pa.	435
Anthony Wayne	150	Saginaw Valley	460
Shreveport	195	Lehigh Valley	475
Arizona	200	Portland	485
Nebraska	200	Indiana	490
New York	218	Stark Central	495
Carolina	245	Fox Valley	500
San Diego	250	Washington, D. C.	500
Northwestern Pa.	280	Columbus	790
J. A. K.	295	Long Island	800
Iowa	300	Northwest	822
Michiana	300	Milwaukee	927
Mobile	300	San Francisco	1154
Peoria	340	Cleveland	1155
Susquehanna Valley	355	Houston (and Sabine)	1540
Iowa-Illinois	370	Chicago	1640
New Orleans	390	Pittsburgh	2168
South Florida	395	Los Angeles	2825

Society News

Henri P. Granjon Selected Adams Lecturer for 42nd Annual Meeting

Henri P. Granjon

Henri P. Granjon, chef de service of the Institut International de la Soudure, Paris, France, has been selected by the Board of Directors of the AMERICAN WELDING SOCIETY to present the 1961 Adams Lecture. The lecturer is recruited each year from the ranks of outstanding engineers and scientists; and the lecture customarily deals with a new and distinctive development in the welding field.

This year's lecture, to be presented at the 42nd Annual Meeting and Exposition in New York City, April 18-20, will cover "Studies on Cracking and Transformation in Steels During Welding." This subject was entered on the agenda of Subcommission B of Commission IX of the International Institute of Welding, which is the reason for selecting this topic for the Adams Lecture. Account will be taken of the Subcommission's work and also of the experience gained on the occasion of various studies undertaken at the Paris Institute of Welding.

M. Granjon, a member of the staff of the French Institute of Welding since 1939, is the French delegate to Commission IX of the IIW and chairman of Subcommission B (Weldability of Steels in Relation to Their Transformation Characteristics) of this commission. He is also vice chairman of Commission XIV (Welding Instruction).

This year's Adams lecturer is currently Headmaster (Director of Studies) and lecturer on metallurgy, testing and inspection at the École Supérieure de Soudure Autogène, a post he has held since 1947.

In 1953, M. Granjon visited the United States as a member of the Mission of the Organization for European Economic Cooperation. He was secretary of the Mission that visited Europe in 1955 in which three members of the AMERICAN WELDING SOCIETY participated.

Kansas Welding Show

The 1961 Kansas Welding Show, sponsored by the Wichita Section of the SOCIETY, will be held in the Kansas National Guard Armory in Wichita on March 24th and 25th.

Primarily educational in nature, the Show will bring the latest in welding equipment processes and allied metals, materials and services to welding users in the Kansas area. It is to be a "working show"—featuring "live" displays and demonstrations.

Show facilities include 17,000 sq ft of display area, ample 220 v power, water and sewage. A large parking area for exhibitors is located directly behind the exhibit hall; and a restaurant will be open for show personnel and visitors.

A standard booth will have a 10-ft frontage on the aisle and be 10 ft deep, with side and back partitions with drapes and your company sign. A professional show company will be available for those wishing to hire special services.

For additional information, contact Chairman M. L. Lampton, Kansas Welding Show, 601 N. Washington, Wichita 14, Kan.

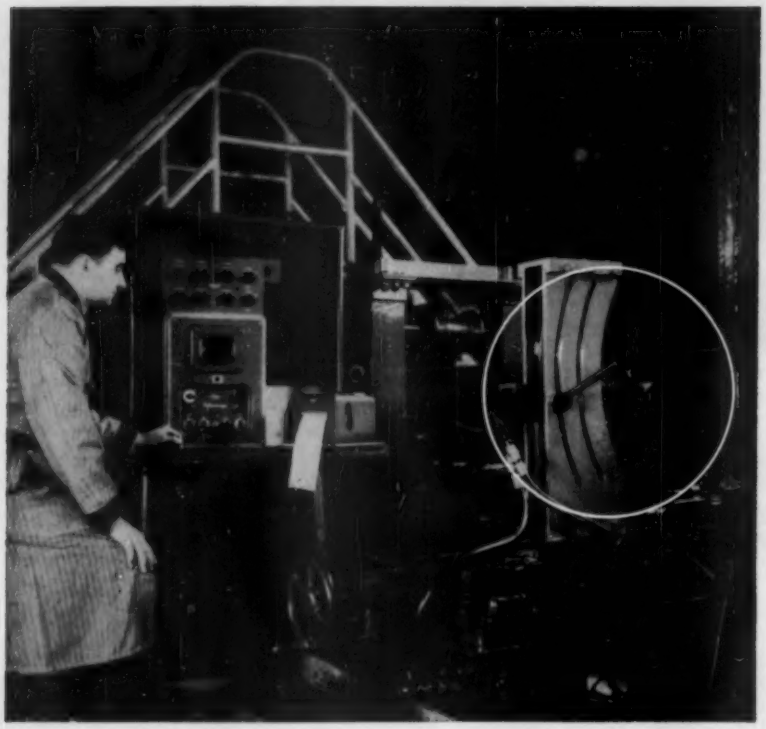
Plans for AWS Spring Meeting Taking Shape

This year New York City will be host to the 42nd Annual Meeting and Exposition of the AMERICAN WELDING SOCIETY in conjunction with the American Institute of Electrical Engineers, April 17–21.

A special feature of the meeting is the Welding Show to be held in the Coliseum with an expected attendance of 18,000. There will be some 23 technical sessions consisting of more than 70 papers, including at least 10 by representatives of European countries. The President's reception and annual banquet, plant tours, the Adams Lecture and education lecture series, to be presented by foreign lecturers, will be scheduled, in addition to a special program for the ladies.

For the first time the International Institute of Welding will hold its Annual Assembly outside Europe. Fifteen technical commissions of the Institute will hold four day meetings in New York, April 12–15. The meetings are restricted to official delegates, experts and observers representing the 27 member nations. Persons representing the United States must be approved by the American Council of IIW.

Considered one of the most highly specialized shows in the United



Sperry Ultrasonic Inspection at 150 feet per minute...

assures pipe weld quality

Sperry ultrasonic engineers, located in all major industrial areas are available for consultation on your automated or manual testing problems.

Call on Sperry experience and research for a solution.

The weld in line pipe for the oil and gas industry must not fail. Yet speed of production also remains an economically important must.

Sperry engineers, working with Jones & Laughlin production engineers, developed a method of integrating the necessary ultrasonic weld inspection into the J & L 150-feet-per-minute electricweld production line.

In operation, the Sperry angle beam search head contacts the pipe as it moves through the mill, and all defect indications are monitored by a Sperry R.A. unit to flash a light, to relay the signal of the defect to a pen recorder and to actuate controls to dye mark the flaw area.

Sperry Products Company

DIVISION OF HOWE SOUND COMPANY

242 Shelter Rock Road, Danbury, Connecticut

For details, circle No. 8 on Reader Information Card

States, the Welding Show will consist exclusively of exhibitors who are manufacturers of welding equipment, material and the like, or products closely related to welding. Exhibit space is more than 90% sold out at press time.

This means that buying power of those attending the Show will be phenomenally high. Statistics indicate that more than 90% have the authority to purchase or specify materials and equipment.

The entire second floor of the Coliseum is reserved for the Welding Show as the exposition promises to be the largest in AWS history.

More than $3,000,000 worth of welding equipment will be on display in the Coliseum in April. Many new products and developments will be uncovered for the first time to make what promises to be a fascinating show.

Meeting headquarters is the Hotel Commodore which will also be the location for the various technical sessions and social activities. Those planning to attend the Annual Meeting are reminded to make their hotel reservations as soon as possible on the approved form and mail it to the AWS Housing Committee.

Welcome

• Sustaining Member

Effective Dec. 1, 1960:

Pennsylvania Power & Light Co.
901 Hamilton St., Allentown, Pa.

This company is an investor-owned business managed electric company supplying residential, commercial and industrial power requirements in a 10,000 sq m Central Eastern Pennsylvania area with a population of more than 2.2 million. The service area has 883 communities with a population of 100 or more, including 67 communities with over 5000 population. Electric power plants owned by the company have a total generation capacity of 1,430,500 kw and electric service is provided to 718,714 customers. The company also supplies steam heat to 1008 customers in the capital city of Harrisburg, Pa.

Sustaining Member Representative—M. D. Engle.

Past Shows Have Been a Great Success . . .

. . . 1961 Show Promises to be The Greatest Yet ! !

Center of AWS activities—
the Commodore Hotel

Scene of the Exposition—
the Coliseum

As in the past, tours for the wives of AWS members—
also shopping along Fifth and Madison Avenues...

Broadway at Times Square after dark—surrounded
by theatres and good eating...

KEEPING YOU POSTED

by Fred L. Plummer

● During November brochures and enrollment forms for the 14th Annual Assembly of the International Institute of Welding were mailed to the welding societies and institutes of 27 member countries for distribution to their individual members, and also to the approximately one hundred members of AWS, WRC and the Ship Structure Committee of NRC who constitute the American Council of IIW.

● On December 15th the official announcement and hotel reservation forms for the 42nd Annual Meeting and Welding Exposition of AWS and the AIEE Electric Welding Conference were mailed to all AWS members and other interested individuals.

● All of these events will take place in New York during the period from Apr. 10 to 21, 1961. Another record-breaking exposition will be housed in the New York Coliseum. The Sheraton-Atlantic Hotel will be headquarters for IIW activities. Center of activities for AWS will be the Commodore Hotel with nearby Biltmore and Roosevelt hotels providing additional sleeping rooms.

● These notes are being written during late December. Already several individuals have enrolled for the IIW Assembly and hotel reservations are being received for the AWS meetings. It now seems probable that these events will bring to New York the largest and most distinguished group of people interested in and intimately familiar with welding equipment and welded fabrication who have ever gathered in one place at the same time. Be sure that you take advantage of this unique opportunity.

● R. H. Chamberlin joined the staff as Assistant Editor of the WELDING JOURNAL on November 21st, replacing Carl Willer who has joined Bonney Rossi on the staff of the Society for Experimental Stress Analysis. N. S. Farrell became Assistant to our Technical Secretary on November 28th and William Waldron became Service Manager on December 19th. These appointments bring your headquarters staff to the full complement of 38 loyal, competent employees as we start another calendar year.

● On November 21st President R. D. Thomas, Jr., and your Secretary joined District Director E. E. Goehringer and Philadelphia Section Officers Walt Wooding, David Buerkel, Frank Hussey and Carl Schaub (who established some kind of a record by joining President Thomas and your Secretary at meetings in York, Baltimore and Philadelphia within a seven day period) for a dinner meeting in the Philadelphia Engineers Club at which President Thomas discussed the use of electroslag welding for heavy fabrication as well as the use of gas-shielded automatic welding of vertical joints in such structures as large field-erected storage vessels.

● Following a few hours sleep in the Airport Motel, very early plane flights transported President Thomas and your Secretary to Pittsburgh and on to Cincinnati where they were met by B. J. Davis who provided transportation during a busy day which included (1) a luncheon at the Hyde Park Golf Club with executives of several of the more important industrial firms in the Cincinnati area, Executive Vice-President E. Forker with associates Klingeman and Gillis of Precision Welder and Flexopress Corp. being hosts, (2) an extended ride over the Cincinnati area in the private plane (Cessna 320) of Mr. Forker, (3) a tour of the plant of Precision Welder and Flexopress Corp., (4) a short visit at the home and with the family of Mr. Davis, and finally (5) the "National Officer's Night" meeting of the Cincinnati Section.

● In addition to President Thomas and your Secretary, Vice-President John Blankenbuehler, Directors Hobart and Schultz, Dayton Chairman Shilbert and seven Past Chairmen of the Cincinnati Section joined Chairman R. G. Gillis, Vice-Chairman M. A. Levinstein, Davis, Kaiser, McKennay, McLain, Rouff and a large group of other members who traveled through a driving rain storm to Cincinnati Industrial Institute to discuss the UEC fund drive, complete plans for an excellent symposium and listen to the challenging discussion of stainless and low-alloy steel welding presented by President Thomas.

● The following morning your Secretary inspected hotel facilities and discussed with representatives of the Convention Bureau and the hotels, the possibility of a future AWS national meeting in Cincinnati, before returning by plane to New York and his office shortly after noon.

● On November 30th Eutectic Welding Alloys Corp. held its 20th Anniversary Celebration during which the "welding" of a time capsule cornerstone, in which WELDING JOURNAL Editor Schoonmaker and representatives of other welding magazines deposited copies of these publications, followed appropriate remarks by Eutectic President Rene Wasserman. This cornerstone is for a new administration building which is part of a $2.5 million metallurgical plant and research center to be added to its world headquarters in Flushing, N. Y., by Eutectic.

● Mrs. Wasserman graciously assisted her husband in cutting a huge anniversary cake at the reception and luncheon at which President Wasserman and Vice-President J. T. Quaas explained expansion plans to the many public officials, representatives of the press and others who participated in this important event. Former AWS Secretary J. G. Magrath, now associated with Eutectic in the direction of educational and industrial relations programs, greeted guests during the plant tour which preceded the dedication ceremonies.

● Your Secretary held important conferences on November 29th with Past-President C. I. MacGuffie, on December 1st with Exposition Manager R. W. Kenworthy and on December 2nd with Treasurer H. E. Rockefeller. A luncheon meeting with AWS Vice-President C. E. Jackson, WRC Director Ken Koopman, WRC University Research Chairman Art Lytle and Mr. Rockefeller followed this last conference and was devoted to a discussion of plans for the annual WRC dinner meeting which will be held on Wednesday evening, April 19th, during the AWS Annual Meeting in New York.

● Journal Editor Ted Schoonmaker and your Secretary were guests with

many press representatives, Bob Fernley of NWSA, officers and representatives of Air Reduction Sales Co. at a special luncheon in Hotel Biltmore for the sweepstakes drawing for grand prizes in the very successful "Cata-Quiz" contest for authorized Airco distributors. Names of 38 grand prize winners were selected by representatives of the press from a barrel containing those of the almost 2000 participants in the contest, as Airco President R. E. Lenhard, Vice-Presidents C. H. Glasier and E. S. Twining, Jr., and associates Berg, Scherer, Goerg, Stone, Sherman, Callahan and others were interested observers.

● R. C. Becker, of International Harvester Corp. and Vice-Chairman of our Chicago Section, was an early visitor on December 7th for a discussion of problems and policies of this important group. Later in the morning Mr. and Mrs. W. Spraragen visited your Secretary prior to departure for a four-month stay in Florida. Mr. Spraragen retired late in May 1960. He and Mrs. Spraragen have established their home in Northport, on Long Island. Their address through March 1961 will be Holiday Hotel, 600 Beach Drive N. E., St. Petersburg, Fla. Still later during this same day your Secretary met with Past-President J. H. Humberstone to discuss plans for the IIW 1961 Assembly.

● Early the next morning your Secretary flew to the Pittsburgh airport to join President Thomas, Past-President MacGuffie and Treasurer Rockefeller at a meeting of the Arc Welding Section of NEMA at which Chairman L. D. T. Berg presided and Secretary R. L. Nims handled arrangements. A. J. Nesti, Chief Statistician of NEMA, presented a realistic appraisal of the electrical manufacturing industry. Secretary Nims gave a brief description of NEMA, the 8 divisions which include the Industrial Equipment Division with 13 sections (of which Welding Section is one of the most important) and almost 400 companies, the Board of Governors, Officers Committee and the Board of Directors for each Division. Other items on the agenda included the formation of a new Economics Committee, consideration of possible participation in the 1964–5 World's Fair in New York, a question concerning the inclusion of welding courses in engineering college curricula, a revision in color marking requirements for electrodes for Federal and Military use and a number of committee reports. Most of the important arc welding equipment and electrode manufacturers were represented at this meeting.

● Mid December conferences in your Secretary's office included one with Bob Bellas of Power concerning a special issue of Power to be devoted to maintenance welding; another with Dr. Werk of the Engineering Foundation concerning the future growth and policies of this important and potentially very influential agency; and a third with NWSA Secretary Bob Fernley concerning the preparation, distribution and use of technical and education literature of special interest to members of NWSA.

● During February President Thomas and your Secretary will meet with AWS Sections as follows: 6, Lehigh Valley at Bethlehem; 9, Long Island; 13, Boston; 14, R. D. T. at Manchester, N. H.; and F. L. P. at Springfield, Mass.; 15, Syracuse; 16, Madison, Wis.; and 17, Appleton, Wis.

PLAN NOW TO ATTEND THE AWS 42nd ANNUAL MEETING AND EXPOSITION IN NEW YORK, N.Y., APRIL 17–21

1. More than 100 exhibits embracing all forms of welding at the Coliseum.
2. Twenty-two technical paper sessions at the Hotel Commodore, including three sponsored by the International Institute of Welding and three sponsored by the American Institute of Electrical Engineers.
3. Plant tours.
4. Activities for the wives of AWS members.

EDUCATIONAL ACTIVITIES

National Welded Products Month

National Welded Products Month is again rapidly approaching—April will soon be here, and with it the Annual Meeting and Welding Exposition. In order to emphasize to the public the importance of welding, this year AWS Sections are making an all-out drive to publicize National Welded Products Month through all possible channels.

All Publicity Chairmen of AWS Sections have already received their 1961 Planning Manual for NWPM. In the Manual are listed the many procedures which can be used to promote April as the month when welding and welded products are brought to the attention of the public.

This month's Educational Activities page may be used as a checklist of items for Publicity Chairmen to consider in their plans for publicizing NWPM in their own districts.

NWPM Committee

Whenever possible, a committee should be formed to assume responsibility for the promotion of NWPM in the area. The scope of the program will be limited if the Chairman attempts to carry the entire promotion on his own. If there are only three members of his committee, he can assign one member to each of three activities. If he can get six members on his committee he can double the scope of his promotion.

If one member of his committee is a salesman, regularly calling upon manufacturers in the area, this man should be assigned to contact the manufacturers and distributors in order to get their cooperation. Other members of the committee may have contacts in civic organizations and the chambers of commerce, in department stores, or in radio and television.

Finally, one very important assignment is to obtain a proclamation from the mayor and from the governor of the state. The proclamation should be the culminating point of all publicity and should be the highlight of the campaign.

Special Projects

Chambers of commerce, convention bureaus and the like are usually very receptive to ideas for special promotions. They will usually work with you to encourage department stores to give window displays. They will help you to arrange with the civic authorities for large welded products such as missiles, trucks, earth-moving equipment and similar equipment which is too large to be housed in a store window. It has been found that banks are very receptive to the idea of devoting space in their bank to a collection of smaller welded products. In many cities, the construction of large and interesting displays in the banks has provided widespread publicity.

Member companies and others can be encouraged to arrange plant tours, open houses and similar activities during the month of April.

Wherever luncheons, dinners and meetings are being held, speakers should be invited who will give short, interesting, informative talks on how welding affects our way of life, promotes our national security and makes constant contributions to scientific progress. There are so many achievements on land, sea, air and space which could not have been achieved without welding. Many interesting stories can be told on these subjects.

If you start this activity early enough you may be able to persuade some of the manufacturers, the civic authorities and retail executives to cooperate with you and to schedule for April any groundbreaking ceremonies, opening of new buildings, additions or new facilities so that they can be tied in with National Welded Products Month promotion.

April is a month when an all-out drive should be made to interest the schools and the students at all levels. Most schools, institutes and colleges are very receptive to a scientific talk. Some of our Sections have given live demonstrations; others have presented an instructive talk, and some have combined a brief talk with a film presentation. A look through our film directory will give you a list of many films which will be suitable for practically all occasions.

AWS Emblems

Wherever advertising is placed it should be possible to use one of the AWS emblems to draw attention to National Welded Products Month.

Again this year we will be providing "Welded Product" stickers which can be used to draw attention to every product which has been welded. The impact of this sticker can be tremendous. Practically every appliance that is sold in a department store is a welded product; every automobile you see on the road is a welded product; if you can get near enough to the jets you could put a sticker on these because they too are welded products. These stickers are available from headquarters upon request.

Another excellent advertising twist is the use of postage meter slugs for use by companies in their postage meters. These slugs may be obtained at a cost of approximately $15 each. Any message desired can be used but, the one we suggest is:

All local advertisers should be encouraged to mention National Welded Products Month in their radio and television commercials. With a little ingenuity, this procedure can draw attention not only to NWPM but also tie it in with their own products and thus capitalize on our national publicity together with their local publicity.

Many companies imprint "National Welded Products Month" on the foot of letterheads. We do this ourselves and have found it an

excellent publicity procedure and one which is widely read by a variety of people all over the world.

Wherever a company issues its own house organ and/or publication, copy should be prepared or a suggestion made that they mention National Welded Products Month in these company publications.

Advantages of NWPM Promotion

This promotion is far from being one-sided. It is one of the few promotional projects where everyone gains. The public gains an understanding of the advantages, the strength and the high efficiency of welded products. Those who are in the welding industry gain by the increased demand for welding and the increased public confidence in weldments. The AMERICAN WELDING SOCIETY gains through the greater acceptance of welding. When calling upon any of these companies or groups with a request for their cooperation, the thought to bear in mind is that in seeking their help you are also asking them to help themselves, because the publicity they are receiving either for their company and their product or the welding industry cannot fail to do them good in the long run.

Any information, assistance or advice will be gladly given by headquarters at any time. All newspaper clippings, photographs and the like should be sent to headquarters in order that we may reproduce these, both in brochures and in the WELDING JOURNAL.

Welcome

• Supporting Companies

Effective Dec. 1, 1960:

Modern Engineering Service Co.
Berkley, Mich.

H. I. Tullis Co.
Long Beach, Calif.

Effective Jan. 1, 1961:

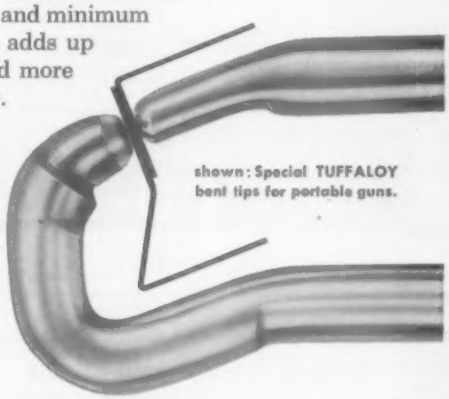
Cottet's Welding Supply Co.
Syracuse, N. Y.

Depke Welding Supplies, Inc.
Danville, Ill.

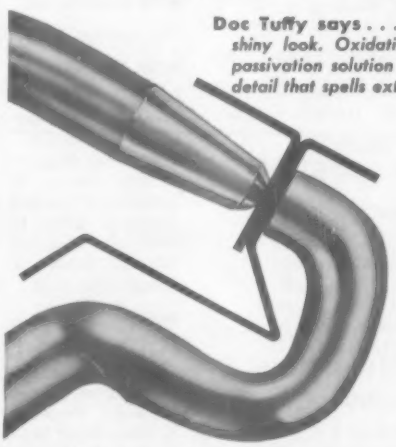
SUPPORT YOUR SOCIETY....
.....BE ACTIVE!

The Strongest Bent Tips Come From TUFFALOY

You get more spot welds for your money when you buy TUFFALOY bent tips. These electrodes are bent to precise angles so skillfully that there's no sacrifice of the wall strength needed to withstand heavy forging pressures. Examine a TUFFALOY bent-tip—the diameter remains constant and the coolant hole is unobstructed. So carefully is the job done that there's no cave-in at the outside of the bend, and minimum swelling at the sides. This adds up to longer electrode life, and more spot welds for your money.



shown: Special TUFFALOY bent tips for portable guns.



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EFFECTIVE DECEMBER 1, 1960

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	198
Members	6,429
Associate Members	5,749
Students	323
Honorary Members	10
Life Members	31
Total	12,740

ALBUQUERQUE

Brown, Van A. (C)
Smith, Carl F. (B)

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Barnett, Albert (C)
Coburn, Chester (C)
Jacobs, George H. (C)
Packer, Clyde N. (C)
Rowland, Ralph (C)

ATLANTA

Straub, Robert C. (C)

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McMurtry, Harold J. (C)

BIRMINGHAM

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Stevens, James S. (C)

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CAROLINA

Holder, H. L. (C)

CHATTANOOGA

Burke, Joseph M. (C)

CHICAGO

Backen, Arthur O. (B)
Cork, H. V., Jr. (C)
Cox, Wiley N. (B)
DeWitt, Ernest W. (C)
Fisher, Jack A. (C)
Honcharevich, Peter (C)
Jamie, Edward F. (C)
Lange, Ralph H. (C)
Leif, Paul David (D)
Lundholm, Roger G. (C)
McGovern, T. J. (B)
Parr, Gerald (B)
Plunkett, C. W. (C)
Rafter, Robert T. (D)
Smith, Ira C. (B)
Taylor, Addison F. (C)
Thompson, Robert E., Jr. (C)

CLEVELAND

Morgan, Keith (C)
Spexarth, Frank A. (B)

COLORADO

De Bruyne, George (C)

COLUMBUS

Bradley, James W. (D)
Cable, Gary L. (D)
Hill, William H. (D)
Hipley, Robert L. (D)
Lewis, Thomas E. (D)
Slemmons, Whit (D)
Wilcox, Leo C., Jr. (D)
Wright, William G. (B)

DAYTON

Eder, Fritz J. (C)

DETROIT

Beattie, George (C)
Benner, Charles E. (C)
Fisher, Oran (C)
Haltom, Ernest Eug ne (B)
Herbart, Carl (B)
Kroy, Ralph E. (B)
Lee, Burny C. (C)
Main, Duane A. (D)
Safilian, Aram (B)
Senn, Charles (C)
Spunar, Theodore Robert (B)

FOX VALLEY

Kolstra, Louis (B)

HARTFORD

Sonntag, Edmund G. (B)

HOUSTON

Dvorak, John J. (B)
Mazoch, A. L. (C)
Melear, Van B., Jr. (C)

INDIANA

Marks, Milton H. (C)
Workman, George D. (C)

IOWA

Richards, Clare (B)

IOWA-ILLINOIS

Bodamer, William H. (B)
Davis, Charles A. (A)

KANSAS CITY

Copenhaver, Harry L. (B)
Dalrymple, Robert G. (B)

LEHIGH VALLEY

Schmura, John A. (B)

LONG BEACH

Eidsness, Richard (D)
Greenwell, George (C)
Johnston, Vernon (C)
Lewis, Howard E. (C)
McGowan, Gordon S., Jr. (C)
Phelps, Stewart C. (D)
Tullis, Richard E. (C)

LONG ISLAND

Irwin, Robert P. (C)
Klarman, Marvin (C)
Martin, Robert H. (B)

LOS ANGELES

Eaglen, Ralph L. (B)
Gates, James R. (B)
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Martin, Charles F. (B)
Norwood, Leland B. (C)
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Irwin, Frank (B)

NEW HAMPSHIRE

McGuiness, Clifford P. (C)

NEW JERSEY

Bridges, William G. (B)
Canulette, Walter N. (C)
Clark, William C., Jr. (B)
Haggerty, Kenneth C. (C)
Hickey, George W. (B)
Iceland, William F. (C)
Johnson, Albert R. (C)
Mollden, Richard Allan (B)
Schaub, Adolph R. (B)
Spies, George R., Jr. (C)

NEW YORK

Forti, Frank J. (C)
Harris, Lawrence (B)
Hochhauser, Irving (C)
Kinelski, Eugene H. (B)
Kouka, Fred H. (C)
LaBua, Anthony (B)
Olsen, Edward E. (B)
Spolianaky, Alex (B)
Steinberg, Matt A. (B)

NIAGARA FRONTIER

Colliver, Michael Davy (C)
Eddy Allen A. (B)
Moody, Bruce R. (C)
Schaefer, Ronald P. (B)
Stormer, Hugh (C)

NORTH TEXAS

Jennings, Clarence H. (B)
Thomas, H. A. Tommy (C)
Treadwell, Stephen S., Jr. (C)

NORTHERN NEW YORK

Alexander, Warren G. (B)
Dinuzzo, Louis J. (B)
Hammond, Leo (B)

NORTHWEST

Doyle, Howard E. (C)
Felstow, William F., Jr. (C)
Mueller, Charles J. (C)
Rogers, Richard E. (B)

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Smith, Bart S. (D)

ORANGE COUNTY

Brown, Dwayne Jack (B)

PHILADELPHIA

Daugherty, Carl (B)
Hemphill, Charles J., Jr. (C)
Rinaldo, Lawrence (D)

PITTSBURGH

Bruckart, William Lee (C)
Brueckner, Edward W. (B)
Collins, Leo F. (B)
Cooper, F. R. (C)
Smith, John R. M. (C)
Sorchy, Steve (C)
Stewart, Willard F. (B)
Stoehr, Robert A. (D)

PORTLAND

Handewith, Howard J., Jr. (B)
Lehto, Howard (D)
Schaefers, Robert J. (D)

PROVIDENCE

Hudson, Clement W. (C)
Rupp, Charles R. (C)

PUGET SOUND

Andersen, Raymond C. (C)
Regan, Richard E. (B)

RICHMOND

Cheatham, B. G. (B)

SAGINAW VALLEY

Dadd, Lester L. (B)
Herzberger, Peter C. (C)
Kaltz, Kenneth (B)
Tack, Marvin C. (C)

ST. LOUIS

Greiling, Paul (C)
Hayhurst, Jack S. (B)
Wahlbrink, Charles L. (C)

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Bruening, Robert A. (C)
Taylor, Keith A. (D)

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SAN DIEGO

Moss, Clarence D. (C)
Walker, Walter M. (B)

SAN FRANCISCO

Besich, Nick P. (B)
Bradley, Richard L. (B)
DaValle, Fred (B)
Neerhout, John, Jr. (B)
Peacock, C. B. (C)
Peck, Richard M. (C)
Smith, Marall Holmes (C)
Smith, Troy E. (C)

SANTA CLARA VALLEY

Archer, E. W. (C)
Bergthold, John H. (C)
Decker, C. D. (C)
Edgar, J. P. (D)
Graves, Robert N. (C)
Husted, Thomas A. (C)
Lutz, David (D)
McGarr, D. M. (D)
Pedersen, Robert A. (C)
Price, George W. (C)
Simpson, S. E. (D)
Spioule, W. F. (C)
Starnes, Duane (B)
Stewart, Dave (D)
Sutherland, Sam (D)
Tirri, Austin, A. (C)
Williams, Richard (B)

SUSQUEHANNA VALLEY

Engle, M. D. (A)

TOLEDO

Gerhardstein, Rodger A. (B)
McSwain, C. B. (B)
Terry, J. Kenneth (B)

TULSA

Siever, Robert Wayne (B)

WASHINGTON, D. C.

Keys, Claude T. (B)
Mason, Ray E. (B)
Scott, Donovan A. (B)
Shingleton, Laurence L. (C)

WESTERN MICHIGAN

Olree, Adrian R. (C)
Swiftney, Robert (C)

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Litzenberger, L. A. (C)

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Starz, Victor H. (B)

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Giuffrida, Vito (B)
Kamimura, Kenichi (B)
Pereira, Roberto Racine (B)
Victoria, Javier Orozco (B)

Reclassifications During December 1960

IOWA

Kennedy, Neil (D to B)

NEW JERSEY

Stone, Robert A., Jr. (C to B)

Tuthill, Roger W. (C to B)

NIAGARA FRONTIER

Bradley, John J., Jr. (C to B)

WASHINGTON, D. C.

Saenger, J. F., Jr. (D to B)

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SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

Arizona

ALUMINUM ALLOYS

Phoenix—"Aluminum Alloys, Their Symbols and Recognition" was the subject of a talk by Harry Pecor given at the November 16th meeting of the *Arizona* Section. He explained the various code symbols and letters used universally in denoting the different alloy content and percentages in the aluminum manufacturing industry.

Mr. Pecor is associated with the Allstate Co., Los Angeles. The dinner meeting was held at the Hi-way House Restaurant.

California

MATERIALS IN SPACE

Los Angeles—Approximately 150 members and guests of the ASM and the *Los Angeles* Section convened at the Rodger Young Auditorium on Thursday, November 17th, to hear a paper of great interest and magnitude presented by Lt. Col. John F. Clyde, who is chief of the Supporting Engineer Division at the Ballistic Missile Div. of the Air Research and Development Command. The subject of his paper was "Materials in Space." Col. Clyde discussed the Air Force's research program in general, describing the manner in which the Air Force is going about planning for the 1965–80 generation of weapon systems. He identified the major technical areas wherein basic and applied research is required in the specific area of materials and processes, describing work now being sponsored by the Air Force and an outline of the demands placed on the U. S. research community to meet the material needs of the coming space age arising from new and severe environments of temperature, radiation and shock encountered by high altitude rocketry and space vehicles. Slides, shown in connection with the talk, depicted various stages of progress in space travel and the essential types of space platforms that would be needed for use as way stations.

A film, in color, entitled "Oxygen Steel" was shown through the courtesy of Kaiser Steel Co.

CHRISTMAS PARTY

Los Angeles—Approximately 210 members and guests convened at the Rodger Young Auditorium, in Los Angeles, on Thursday evening, December 8th, to enjoy one of two big social events held annually by the *Los Angeles* Section. This meeting—the annual Christmas "Stag" party—loaded with talented, graceful and vivacious entertainment, was one of the best ever held.

Thirsts were quenched and hunger appeased with a delicious 12-oz. steak dinner, which was followed by the evening's entertainment with Buzzy Green, burlesque commedienne, serving in the capacity of master of ceremonies and keeping the audience in laughter during the entire time. The show included: Jade Rhodora as "Beauty and the Beast" in delightful, daring and exotic dancing; Gwen Dolyne in "More Bounce to the Ounce" which was very sophisticated and provocative; and the mad musician, Harry Nelson, whose exceptional talent made it possible for him to extract music from practically any known piece of hardware. The program was concluded with the drawing of numerous door prizes.

Preceding the evening's program, entertainment was provided during the cocktail hour and dinner by the lovely Miss Francine Fay on the accordion.

ELECTRON BEAM WELDING

Rancho Cordova—The *Sacramento* Division of the San Francisco Section held its monthly meeting at Cordova Lodge on the evening of October 26th. R. A. Stone, sales manager, Special Products Dept., Air Reduction Co., discussed the "Electron Beam Welding Process and Its Applications."

Mr. Stone's illustrated talk traced

MOMENTS TO REMEMBER IN LOS ANGELES

Joint meeting with ASM on November 17th where Lt. Col. J. F. Clyde was guest speaker. Left to right are: W. V. Ward of ASM, Col. Clyde, John Wiley and Al Collins

Pre-Christmas festivities where Miss Fay was one of several lovely entertainers on December 8th. Seated left to right and listening to Miss Fay are: George Rossner, R. S. Clude, Glen Harmon and Bob Frick

the history of electron beam welding from its inception up to the current status of the process. His presentation detailed the design and function of the electron beam gun and required vacuum system. He concluded the evening with an interesting discussion of prospective applications for the process.

NONDESTRUCTIVE TESTING

Rancho Cordova—The *Sacramento* Division of the San Francisco Section held a joint meeting with the Society for Nondestructive Testing at Cordova Lodge on the evening of November 16th. Robert B. Oliver, national president of the Society for Nondestructive Testing and Head of the Nondestructive Testing Section of the Solid Rocket Plant Quality Control Division, Aerojet General Corp., Sacramento, was the guest speaker. His subject was "Fundamentals of Nondestructive Testing in the Field of Welding."

Mr. Oliver's slide-illustrated talk

SECTION MEETING CALENDAR

FEBRUARY 8

CLEVELAND Section. Cleveland Engineering and Scientific Center. Cocktails 6:00. Dinner 6:30. Meeting 8:00. "Resistance Welding."

FEBRUARY 9

ALBUQUERQUE Section. 7:30 P.M. Tour of Ideal Cement Plant in Tijeras Canyon.

FEBRUARY 10

DETROIT Section. Engineering Society of Detroit. 8:00 P.M. "Epoxy Pak Transformers," W. G. Emans, Jr., Kirkhof Mfg. Co.

FEBRUARY 21

OLEAN-BRADFORD Section. Castle Restaurant, Olean, N. Y. Dinner 7:00. Meeting 8:30. "Large Weldments Fabrication," John Latreyte Lang, Lukenweld Div., Lukens Steel Co.

MARCH 2

NORTH CENTRAL OHIO Section. Plant Tour.

NORTHERN NEW YORK Section. Hot Shoppes, Route 9, Albany, N. Y. Dinner 7:00. Technical Session 8:00. "Brazing of Stainless Steels for High-temperature Service," R. L. Peaslee, Wall Colmonoy Corp.

SAGINAW VALLEY Section. Saginaw, Mich. D. C. Smith, Harnischfeger Corp.

TOLEDO Section. Clinic—Design of Welds and Welded Joints. "Structures and Structural Welding."

MARCH 6

LEHIGH VALLEY Section. Walp's Restaurant, Allentown, Pa. Dinner 6:30. Technical Session 8:00. Joint Meeting ASCE. The Manufacture of Expanding Line Pipe for the Gas Industry, Eric Humphries, Bethlehem Steel Co.

OKLAHOMA CITY Section. Cattleman's Cafe, Oklahoma City. Dinner 6:30. Meeting 7:30. Welding of T-1 Steel, L. K. Keay, Lukens Steel Co.

MARCH 7

TULSA Section. Danners Cafeteria, Tulsa, Okla. Aircraft Welding.

MARCH 9

IOWA-ILLINOIS Section. Highland Park Bowl, Moline, Ill. Dinner 6:30. Meeting 7:30. Resistance Welding. General Fundamentals, Applications and Controls.

J. A. K. Section. Aurora, Ill. Nondestructive Testing.

ST. LOUIS Section. Ruggeri's Restaurant, St. Louis, Mo. Atomic Submarine Power Plants, Roy Lorentz, Combustion Engineering.

SUSQUEHANNA VALLEY Section. Joint meeting with ASM. Foot Hills Manor, Shickshinny, Pa. "The Welded Heat Affected Zone," E. F. Nippes, Rensselaer Polytechnic Institute.

TOLEDO Section. Clinic—Design of Welds and Welded Joints. "Aluminum Welding."

MARCH 10

COLUMBUS Section. Joint meeting with North Central Ohio Section. "It Isn't Mud," H. F. Reid, McKay Co.

NORTH CENTRAL OHIO Section. Joint meeting with Columbus Section. "It Isn't Mud," Harry Reid, McKay Co.

MARCH 13

BOSTON Section. Plant visitation.

NORTHWEST Section. Minneapolis, Minn. Ladies Night. Peter McKinney, manufacturer of synthetic star sapphires.

MARCH 14

BIRMINGHAM Section. "Welding as it Applies to Missile Construction," William A. Wilson, National Aeronautics and Space Administration.

NORTHWESTERN PENNSYLVANIA Section. Erie, Pa. "Gas-cutting."

DAYTON Section. Kuntz's Cafe. Social 6:30. Dinner 7:00. Meeting 8:00 P.M. "Aluminum Welding."

SANGAMON VALLEY Section. Decatur, Ill. "Product Design for Welding," John Mikulak, Worthington Corp.

WESTERN MASSACHUSETTS Section. Oaks Inn, Springfield, Mass. Dinner 6:30. Technical Session 8:00 P.M. "Welding Machines and Power Supplies," Emil F. Steinert, Westinghouse Electric Corp.

MARCH 15

HOUSTON Section. Field trip to American Bridge Co., Beaumont, Texas.

PEORIA Section. Vonachen's Junction. Dinner 6:30. Meeting 8:30. "Welding Atomic Submarines."

MARCH 16

BATON ROUGE Section. High School Science Contest. "Automatic Welding," J. A. Headapohl, Hobart Bros. Co.

BEAUMONT Section. Field trip to American Bridge Co., Beaumont, Texas.

IOWA Section. "Product Design for Welding" John Mikulak, Worthington Corp.

MADISON Section. Madison, Wis. "Jet Piercing," J. J. Calaman, Linde Co.

MAHONING VALLEY Section. Victoria Restaurant, Youngstown, Ohio. Dinner 7:00. Meeting 8:00. "Welding the Atomic Submarine Triton," G. W. Kirkley, Electric Boat Div., General Dynamics.

MICHIANA Section. South Bend, Ind. "Fundamentals of Arc Welding," H. M. Gregoire.

TOLEDO Section. Clinic—Design of Welds and Welded Joints. "Brazing of Thin Materials."

MARCH 17

FOX VALLEY Section. Van Abel's, Hollandtown, Wis. 7:30 P.M.

MARYLAND Section. Engineers Club, Baltimore. Dinner 6:30. Meeting 8:00. "Metal Spraying Processes," Emil J. Fret, Metallizing Eng. Co.

MILWAUKEE Section. Ambassador Hotel. Buffet Dinner 6:30. Meeting 8:00. "Latest Developments and Use of High-nickel Welding Materials," K. M. Spicer, International Nickel Co

MARCH 20

HOUSTON Section. Corpus Christi Division. "Power Sources for Arc Welding," O. C. Buenger, Airco.

PHILADELPHIA Section. Engineers Club, Philadelphia, Pa. Dinner 6:30. Meeting 8:00. "Design of Weldments Incorporating Steel Castings," Sam Gerhart, Jr., Birdsboro Corp.

MARCH 21

MOBILE Section. Korbet's Restaurant, Social Hour 6:30. Dinner 7:15. Technical Session 8:00.

OLEAN-BRADFORD Section. Castle Restaurant, Olean, N. Y. Dinner 7:00. Meeting 8:30. "Electron Beam Welding," William Farrell, Sciaky Bros.

MARCH 23

NIAGARA FRONTIER Section. The Cypress, Buffalo, N. Y. "Materials for Nuclear Reactors," Marcel Cordovi, Inco.

TOLEDO Section. Clinic—Design of Welds and Welded Joints. "Pressure Vessel and Code Welding."

MARCH 24

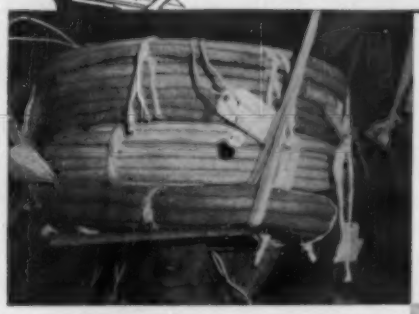
HOUSTON Section. Austin Division. Villa Capri Restaurant. "Submerged-arc Welding of Structures," D. C. Ransone, The Linde Co.

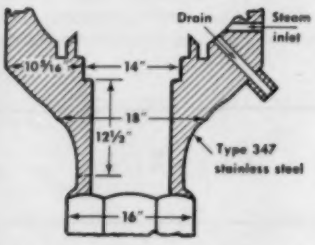
MARCH 29

SAN FRANCISCO Section. Central Valley Division. Sacramento, Calif. "New Developments in Welding and Their Applications," Harry Schwartzbart. Armour Research Foundation.

Editor's Note: Notices for May 1961 meetings must reach JOURNAL office prior to February 20th, so that they may be published in the April Calendar. Give full information concerning time, place, topic and speaker for each meeting.

Profit through E.A.I. Research





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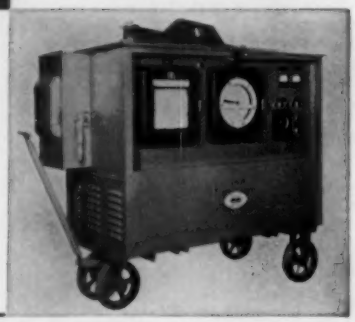

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A typical application of the system by a public utility was described in a recent article in Welding Design & Fabrication.* At Consolidated Edison's No. 10 Turbine Generating Station in New York City, two large steam pressure valves made of Type 347 stainless had to be repaired because of weld embrittlement. Removal to the shop for heat treatment would have proved costly and time taking. With the Smith-Dolan portable units, the work was completed on the job within 12 hours.

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presented the basic fundamentals of the four most-used nondestructive testing methods in use today. He discussed the advantages and limitations of each method.

A panel, composed of Mr. Oliver, S. M. Joseph, nondestructive testing group leader at Aerojet, Paul Jonas, welding engineer with the State Division of Highways, and George Hickox, welding engineer, Aerojet, afterwards conducted a lively and interesting question-and-answer period.

EXPLOSION WELDING

Sunnyvale—The *Santa Clara Valley* Section met on November 22nd at Sabella's Restaurant for dinner and meeting.

Dr. Donald Davenport, assistant director of Poulter Laboratories, Stanford Institute, Menlo Park, Calif., discussed the welding of similar and dissimilar metals using a controlled explosive technique developed recently at their laboratories.

Dr. Davenport stated that the laboratory work has been under study for about a year with very promising results. It is felt that, within two years, various firms will probably be using the technique in production operations. He explained that the welding operation takes place as a result of controlled use of explosives which drive the metals together. Explosive welded metal cross sections, when investigated by optical microscopy, show a rippled surface within the joint which proves a strong mechanical bonding. It was stated that diffusion bonding can be achieved with some metals. The welding is accomplished without the use of a third material between the materials being welded; for successful welds, it is necessary to provide a vacuum between the surfaces of the metals being joined. It is felt that the explosive technique may be especially useful in cladding hard-to-combine metals.

Virtually all work to date with explosive welding has been of an experimental nature. Profound changes occur as a result of the explosive loading and much interesting work in this field remains to be done. It offers great promise as a new technique in the field of hard-to-join metals.

Colorado

WELDING T-1 STEEL

Denver—The *Colorado* Section met on November 15th at Cavaleri's

DISCUSSES ALUMINUM

Guest speaker Roy Frenz at the October 21st Chicago Section meeting

Restaurant. The group gathered at 6:30 for an appetizer followed by dinner.

Richard S. Rote, technical service engineer for Lukens Steel Co., Coatesville, Pa., was the main speaker. His topic was "Fabrication and Welding of T-1 Steel." He discussed the basic characteristics of T-1 steel as well as the need to acquire an understanding of the techniques required for welding. Welding procedures, test results, manual and mechanized submerged-arc welding techniques were also covered.

Connecticut

SAFETY RULES

Bridgeport—Paul Croteau of Smith Welding Equipment Corp. was the guest speaker at the November 16th meeting of the *Bridgeport* Section held at the Fairway Restaurant. The title of his talk was "The Safe Use of Oxyacetylene Welding Equipment."

Mr. Croteau started his talk with the usual safety rules and then went on to explain and illustrate each one, using a torch, gas and regulators to show the dangers involved. By means of colored balls pinned on a board he showed the chemical reactions of making acetylene. This talk was an eye-opener since gas cutting and welding is frequently taken for granted and few heed the dangers. Mr. Croteau gave this talk to several shops after the meeting as it was felt that operators should be "safety-wise."

Florida

CERTIFICATION

Hialeah—The *South Florida* Section and the Miami chapter of the Society for Nondestructive Testing were hosts to 28 members and guests at a dinner meeting held on November 16th at the Park Lane Cafeteria.

Guest speaker was James C. Thompson, Jr., supervisor of inspection, Mechanical Inspection Dept., Union Carbon Nuclear Co., Oak Ridge, Tenn. The subject of his talk was on "Welders Certification and Inspection." A sound movie and technical slides were shown in conjunction with the lecture.

Illinois

INERT-GAS PROCESSES

Chicago—Culver Heffernon, assistant region manager—Electric Welding, Linde Co., addressed the *Chicago* Section on November 18th, discussing gas-shielded-arc welding principles. Nearly one hundred members and guests were treated to an excellent review of the subject matter which was presented in three phases: (1) gas-shielded metal-arc welding, (2) the tungsten-arc process and (3) automatic applications of gas-shielded metal-arc welding. All angles of the talk were well covered by slides, film strip and movies.

SAFETY SEMINAR

Chicago—Roy C. Becker, assistant general supervisor of welding research, International Harvester Co., presented a paper at the Welding Safety Seminar which was sponsored by the Greater Chicago Safety Council in cooperation with the American Society of Safety Engineers and the Society of Casualty Safety Engineers at the Conrad Hilton Hotel on Nov. 17, 1960. Approximately 185 persons attended this Seminar.

Mr. Becker's paper was enthusiastically received since he not only had a very well prepared paper but also had some convincing demonstrations.

ALUMINUM TANKS

Chicago—Roy Franz, welding engineer, Graver Tank & Manufacturing Co., East Chicago, Ind., presented a paper on "Shop Fabricated Aluminum Pressure Vessels and Field Erected Storage Tanks" at the October 21st meeting of the *Chicago* Section held at Peoples Gas Auditorium. Mr. Franz covered power sources, types of inert gas coverage, as well as the particular aspects of aluminum welding such as technique, cleanliness and filler wire. He also discussed automation as used at the Graver plant.

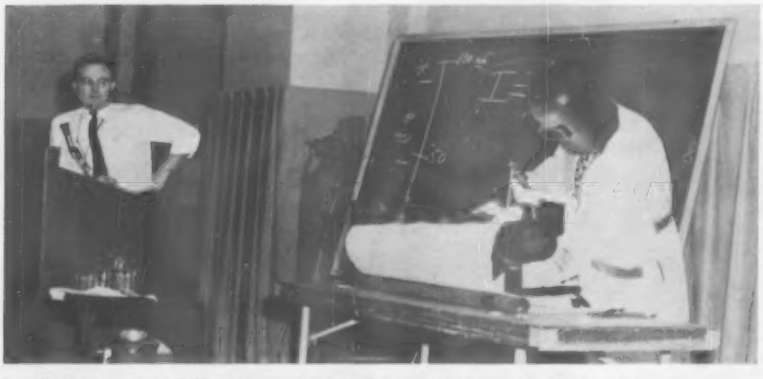
STEEL

Peoria—Frank Boucher of Lincoln Electric Co., Cleveland, Ohio, spoke on "Welding with Semi-automatic and Automatic Processes" at the November 16th meeting of the *Peoria* Section held at Vonachens Junction. In doing so, he emphasized progress made with the Innershield process and indicated that a large number of Innershield welding machines are now being used by several firms.

EDUCATIONAL SEMINAR

Peoria—An educational seminar co-sponsored by ASM and the *Peoria* Section was held on the afternoon of December 3rd at Jobst Hall, Bradley University, with 106 members and guests of

CHICAGO SECTION DEMONSTRATES SAFETY



Roy Becker and H. Kolba demonstrate safety principle on November 17th during welding safety seminar attended by 185 persons

SPEAKS ON GASES

Industrial gases was the topic of talk by B. Gray at the Anthony Wayne November 21st meeting. Left to right are: Bill Love, B. Gray and Walt Hardrock

both societies in attendance. Speakers at this seminar were Elliot S. Nachtman, director of research and development of the LaSalle Steel Co.; Dr. JoDean Morrow, associate professor, Theoretical and Applied Mechanics, University of Illinois; and LaMotte Grover, senior design engineer, Air Reduction Sales Co.

Mr. Nachtman spoke on the "Strength of Materials." Topics in his talk included dispersion hardening, deformation of austenite prior to transformation to martensite, deformation of hot rolled structures at elevated temperatures to improve mechanical properties and machinability of stainless steels at very low temperatures, deformation and precipitation hardening of ferrous and nonferrous alloys.

Dr. Morrow's discussion on "Strength of Structures" brought out that nucleation points for cracks must be entirely present or be produced on a microscopic scale by repeated loading. He also mentioned that nucleation and propagation required that slip or plastic strains take place while the final fracture is of a brittle nature with the crack traveling at high speed through nominally elastic material. Mr. Grover compared correct vs. incorrect design in welded structures and spent some time discussing various means of fabrication.

This type of discussion should be included in the required curriculum of all welding, stress and design engineers.

Indiana

INDUSTRIAL GASES

Fort Wayne—The November 17th meeting of the *Anthony Wayne* Section was held at the Colonial Restaurant.

Twenty members and guests attended the dinner meeting at which B. Gray, engineer with Air Reduction Sales Co., Chicago, Ill., gave a semitechnical talk on Industrial Gases.

ELECTRON BEAM WELDING

Cumberland—The November meeting of the *Indiana* Section was held at Buckley's Restaurant on November 18th with 34 members attending. Following the dinner and recognition of members present, the guest speaker was introduced as Robert S. Stone, sales manager of the Special Products Department of Air Reduction Sales Co. Mr. Stone spoke on "Electron Beam Welding," which covered his company's research activity with this newest metal joining process.

According to Mr. Stone, Air Reduction initiated electron beam welding research approximately twenty-seven months ago and is now marketing the necessary equipment. Electron beam welding was described as a metal joining process in which a beam of electrons is accelerated through a high potential in a vacuum and focused on the weld joint with the kinetic energy of the impinging electrons generating the required heat to weld the parts. One important advantage of the process is the intense energy input which can be focused on a very small area, thereby making it possible to join some dissimilar metal combinations not commonly joined with conventional processes. The weld width and the extent of the heat-affected zone are also minimized.

Square butt or lap joints are commonly used with the process. With more recent equipment advances, filler wire can be added to the joint. On the other hand, filler metal can be designed into the base metal joint geometry. The joining of refractory type of exotic metals is presently the most attractive application of the process.

The talk was supplemented by slides and actual weld samples. It closed with a lively discussion period.

Iowa

WELDING ALUMINUM

Des Moines—Thirty-five members of the *Iowa* Section heard Howard E. Adkins, welding specialist of the Kaiser Aluminum and Chemical Sales, Inc., discuss the "Practical Aspects of Welding Aluminum" at the November 17th meeting held at the Hotel Kirkwood.

Mr. Adkins' talk covered eight points in the welding of aluminum: (1) Aluminum alloys and alloy selection; (2) Comparison of aluminum

NATIONAL OFFICERS AT FALL MEETINGS

On November 18th, President R. D. Thomas, Jr., and National Secretary F. L. Plummer spent a thoroughly enjoyable evening with the Baltimore Section. Here President Thomas (seated second from left) is surrounded by Baltimore past chairmen

Three evenings later both men had an equally enjoyable time with the Philadelphia Section. Left to right are: Frank Hussey, D. H. Buerkel, President Thomas, W. H. Wooding, E. E. Goehringer and Secretary Plummer

PAST CHAIRMEN

Past chairmen of the Saginaw Valley Section are acknowledged at December 1 meeting. Left to right are: P. Thorne, S. Fisher, R. Woollard, F. Williams, W. Moehring, C. Molenaar and D. Knight

and steel welding; (3) Equipment required and recommendations for the production use of inert-gas tungsten-arc and inert-gas metal-arc welding; (4) Cleaning and oxide removal and preparation for welding; (5) Shielding gases and recommendations; (6) Porosity in welding aluminum and its control; (7) Filler wire selection; (8) Practical aspects on techniques recommended.

Michigan

OBTAINING COOPERATION

Saginaw—Dr. Adolph Klautsch of the General Motors Institute in Flint was the speaker at the December 1st dinner meeting of the *Saginaw Valley* Section held at Hi-Life Inn with 72 members and guests present. Dr. Klautsch's talk was concerned with obtaining cooperation between industry and management.

New Jersey

ALUMINUM WELDING

Newark—Matthew J. Waite, Arcos Corp., Philadelphia, Pa., spoke on "Practical Aluminum Welding" at the *New Jersey* Section monthly meeting on November 15th at the Essex House in Newark.

Mr. Waite described the different processes to weld aluminum and the prerequisites for a good weld. He prefers the use of argon gas in welding and stressed need for good filler wire that is clean and level wound and with the proper cast. He also pointed out that high speeds in conjunction with mechanization are an advantage in any aluminum welding process.

The talk was highlighted with a color film entitled "High-Speed Aluminum Welding."

Tremendous interest in the subject was evidenced by the discussion period following the talk which put a number of good questions on the floor.

New York

MEMBERSHIP NIGHT

Bellmore—The annual Membership Night meeting of the *Long Island* Section was held on December 8th at Sunrise Village in Bellmore. As has been customary in past years, light entertainment was provided in the person of Don Engstrand, a professional magician, and by a sound-color motion picture of the Republic Aviation F-105 Thunderchief. New members were introduced and provided with free dinner tickets for the January meeting.

ULTRASONICS

New York — The November meeting of the *New York* Section was held jointly with the Society for Nondestructive Testing on November 9th at Victor's Restaurant.

A very informative introduction to ultrasonic testing methods was presented by John E. Bobbin of Branson Instruments, Stamford, Conn. Lecturing under the general title "Nondestructive Weld Testing of Space Age Vehicles," he began his talk by emphasizing the need for quality control in this critical field. After briefly listing several methods of nondestructive testing, the speaker concentrated on the fairly new field of ultrasonics.

PRESENTATION AT LONG ISLAND

Al Lofsten (left) presenting chairman's key to Past Chairman Keith Berry at December 8th meeting with Ross Harrigan looking on

Each step in the ultrasonic test method was clearly outlined and explained. Various types of transducers were mentioned, together with methods of location to ensure accurate results. There are several present-day applications for this form of nondestructive test which lends itself to virtually all types of production. It was apparent from the questions posed by the audience that many of those in attendance were becoming involved with the finer details of ultrasonic testing for the first time. Although much has been published on the subject, Mr. Bobbin's clear and concise method presentation appealed to all.

STEEL

Buffalo—Nearly one-hundred members of the *Niagara Frontier* Section turned out to hear National Officers speak at Cypress Gardens Restaurant on October 27th. Secre-

HALLOWEEN FESTIVITIES IN BUFFALO

Few of the many members and guests of the Niagara Frontier Section who met on October 27th and heard talks by President R. D. Thomas, Jr., and National Secretary F. L. Plummer

EXAMINE ALUMINUM STRUCTURE

Aluminum welding was the subject at the December 1st Northern New York meeting. Standing left to right are: C. H. Kreisler, J. Cuturilo, Ivan MacArthur, who was guest speaker, and Lee Walker

tary Fred Plummer spoke on the growth of the SOCIETY and District Director Joseph Kehoe further illustrated this point in discussing the progressive movement of the SOCIETY in the western areas of Pennsylvania and New York.

"Some Dramatic Applications of Stainless and Low-alloy Steel Welding" was the subject of a talk by President R. D. Thomas, Jr., who is also president of the Arcos Corp. A broad range of applications were covered from wine storage in the hulls of ships to precision weldments for atomic reactors. This visual presentation was excellent, and much interest in the subject was evident from the question period that followed.

Because the meeting took place near Halloween, a colorful array of decorations festooned the rooms and tables. Altogether this was a very well attended, interesting and enjoyable meeting.

ALUMINUM

Albany — Ivan MacArthur, of Olin Mathieson Chemical Corp., presented an interesting talk and movie on "Aluminum Welding Metallurgy and Processes" at the December 1st meeting of the *Northern New York* Section held at Hot Shoppes, Inc., Albany. His discussion covered the basic problems encountered in aluminum welding and traced its development from infancy to welding's present position as the most widely used method of joining aluminum. The advantage in using manual or automatic welding processes for fabricating pressure vessels and other thick sectioned aluminum products was clearly emphasized.

North Carolina

METAL REMOVAL

Greensboro—The *Carolina* Section held its monthly meeting at Stamey's Barbecue on October 17th. The members enjoyed a talk by Edward K. Moffly on the topic of "High-Speed Metal Removal." Mr. Moffly is manager of the Resin Bonded Division of A. P. deSanno & Sons, Inc., Phoenixville, Pa. The manufacture of grinding wheels was described, and slides of production and testing procedures were shown. In addition to his explanation of types of grinding wheels and their uses, Mr. Moffly pointed out some of the hazards encountered in grinding. He stated that, along with the proper wheel for the job, correct and properly maintained equipment is the secret of safe grinding.

SPEAKER GREETED

E. K. Moffly (center) was guest speaker of the Carolina Section on October 17th. Standing with Mr. Moffly are Jim Martin (left) and Herb Owen

Ohio

CUTTING PANEL

Columbus—On Friday, December 9th, a dinner meeting and technical session of the *Columbus* Section was held at the Florentine Restaurant. A happy half-hour of fellowship preceded the dinner.

The technical session consisted of a cutting panel with the following members who gave short discussions: Robert Rugh, W. C. DeLille Co., "Hand Cutting"; Norman Carl, Burdette Oxygen Co., "Cutting Machines, Past, Present and Future"; Don Carey, Air Reduction Sales Co., "Oxygen Purity and Flame Cutting"; R. O. Simmons, Linde Co., "Factors in Fuel Gas Flames"; Howard Balthasar, Welding and Mechanical Supplies, Inc., "Trouble Shooting in Machine-Cutting Problems."

The panel was assisted by John Purdy of the Buckeye Steel Casting Co. and by Richard Grant of Jaeger Machine Co. during the answering of questions.

ELECTRODE COATINGS

Dayton—The second meeting of the 1960–61 season of the *Dayton* Section was held at Kuntz's Cafe on Tuesday, November 15th. A delicious fried chicken dinner was enjoyed by all present.

An entertaining wild-life film was shown preceding the speaker of the evening, Thomas Ferris. A development engineer at Hobart Brothers Co., Mr. Ferris spoke on the subject of development of manual arc welding electrodes. Charts showing typical ingredients which go into coating formulations of the common mild steel electrodes helped illustrate the talk.

NOTED SPEAKER DISCUSSES MACHINE CUTTING

Vice-President A. F. Chouinard as he addressed the Stark Central Section on November 17th

CUTTING IS THE TOPIC

Chairman C. J. McGeady is shown with Cliff Anthes (left) who was guest speaker at the Lehigh Valley Section on December 5th

OIL TANKS

Bucyrus—The *North Central Ohio* Section met on December 1st for dinner and meeting at the American Legion in Bucyrus.

L. J. Christensen, assistant welding engineer for the Chicago Bridge and Iron Co., presented a very interesting lecture about the erection of oil tanks in the Middle East in a general discussion on the erection of pressure vessels. He explained some of the welding procedures used. His lecture was accompanied by some very interesting color slides.

OXYGEN CUTTING

Alliance—The *Stark Central* Section held its November meeting on Thursday, the 17th, at Polinori's in Alliance.

A fine crowd turned out to hear A. F. Chouinard of National Cylinder Gas Co., and vice president of the SOCIETY, speak on "Machine Cutting Equipment and the Evaluation of Various Fuel Gases." Although this was a broad subject and one that demanded more time than was available, Mr. Chouinard's presentation was exceptional.

Following his opening remarks, he spoke of the development of machine cutting to the present and opened new areas of thought as to what we might expect in the future. The subject was handled in a clear, comprehensive manner that found favor with his listeners and was garnished with things learned from research and a broad personal experience that is distinctive.

Slides used throughout the lecture helped his listeners to a well-rounded understanding of the subject under discussion. They also helped to lay the foundation for the many questions that were asked at the end of the lecture. Questions from the group attested to the great interest in the speaker's presentation.

Oregon

WELDED GIRDERS

Portland—E. H. Weil, district manager of the Lincoln Electric Co. in Portland, presented his paper on "Record Size Welded Girders" before the November 9th meeting of the *Portland* Section held at Henery Theiles Restaurant. An excellent description of the fabrication of these girders in the shop and field, both manual and semiautomatic submerged-arc welded, was given by Mr. Weil.

Pennsylvania

POWER SUPPLIES

Johnstown—The *Johnstown* Sub-Section of the Pittsburgh Section met on November 18th. There were 49 members and guests present. This is a cross section made up of production supervisors, foundry, metallurgical, production planning, maintenance and service and supply shops.

G. K. Willecke, director of research, Miller Electric Manufacturing Co., gave an excellent presentation keyed to answer and clarify some of the questions in the minds of users of welding equipment as to the characteristics of specific welding machines, including their capabilities and limitations, particularly in the field of a-c transformers and ac–dc power sources with both silicon and selenium rectifiers.

FUEL GASES FOR CUTTING

Allentown—*Lehigh Valley* Section held their monthly dinner meeting at Walp's Restaurant, Allentown, on December 5th with Prof. C. J. McGeady, Section chairman presiding.

Following dinner, Boice McCain from Calonia, N. J., a student at Lafayette College, showed color slides and spoke of his travels and his work last summer in a steel foundry at Varde, Denmark. Mr. McCain was an International Exchange Student.

The technical meeting speaker was Cliff Anthes of the Development Laboratory, Linde Co., Newark, N. J. His subject was "Oxy-natural Gas Cutting." He discussed the equipment to use and the torch adjustments that should be used to obtain the best heat from propane and natural gases. He told of the problems that come from using fuel gas and how to correct them. He showed slides of various ratios of preheat oxygen to volume of natural gas and propane gas to preheat starting time and compared these ratios. Slides of curves of natural and propane gas flow to preheat start time were also shown.

NONDESTRUCTIVE TESTING

Schickshinny—Warren J. McGonnagle of the Argonne National Laboratory was the guest speaker at the December 7th dinner meeting of the *Susquehanna Valley* Section held at Foot Hills Manor. The subject of his talk was "Nondestructive Testing of Weldments."

Dr. McGonnagle expertly covered the entire field of nondestructive testing, emphasizing that the role of welding engineer and nondestructive testing engineer must be a cooperative endeavor rather than

POWER SUPPLIES FOR JOHNSTOWN

Part of gathering which heard G. K. Willecke discuss transformers and power suppliers on November 18th

NATIONAL OFFICERS DINED AT YORK

Part of York-Central Pennsylvania Section which met on November 15th to hear President R. D. Thomas, Jr., and National Secretary F. L. Plummer

the "I'll hide the flaws—you try to find them" affair that it is in many circumstances. He summarized the many methods of nondestructive testing currently in use and also those which are in the process of development. These range from X-ray—currently receiving the greatest use—through ultrasonics, thermal leak detectors, dye penetrant inspection, thermal imaging, secondary radiation, eddy currents and visual inspection with the latter being one of the most important methods.

He stated that the three primary objectives of the nondestructive testing engineer are as follows: (1) To develop methods of nondestructive testing using adequate instrumentations, (2) to improve the present methods of testing and (3) to ensure adequate quality of production with the available methods of testing.

AWARD FOR NASHVILLE

On October 13th presentation of Henry Neitzel Award for the greatest percentage membership increase for the year, 1958-59. Left to right are: Nashville Section Membership Chairman W. M. Belen, W. P. Regen and Vice-President J. H. Blankenbuehler

ALLOY STEELS

West York—President R. D. Thomas, Jr., and Secretary Fred L. Plummer were the guest speakers at the November 15th dinner meeting of the *York-Central Pennsylvania* Section held at the Viking Club in West York.

Mr. Plummer, as coffee speaker, outlined the functions of the SOCIETY personnel and committees, and the new engineering building. He also described the objectives of the International Institute of Welding, of which he is vice president and which is made up of representatives of the welding societies and institutes of 28 nations.

Mr. Thomas gave a very enlightening presentation of "Some Dramatic Applications of Stainless and Alloy Steel Welding." Starting with a constitutional diagram for stainless steel weld metal, the uses of such steels were described, starting with the lowest alloy content and progressing to higher alloy compositions. Welding processes and weld metal compositions best suited to each case were brought out.

He mentioned the requirements of low-alloy weld metals—mainly high yield, tensile strength and notch toughness. Mr. Thomas stated that 10% of all electrodes sold in this country are of the stainless and low-alloy steel types. This percentage is far greater than that used by European countries.

The presentation was very well illustrated by slides showing actual applications.

Rhode Island

GAS-SHIELDED-ARC WELDING

Providence—The *Providence* Section held their monthly dinner meeting at Johnson's Hummocks on Wednesday, December 14th.

J. A. Howery, divisional service representative for the National Cylinder Gas Co., presented an interesting talk on gas-shielded-arc consumable-electrode welding. He used slides and sound movies to illustrate his subject.

Tennessee

PLANT TOUR

Kingsport—The *Holston Valley* Section held its regular dinner meeting on November 15th at Skoby's Restaurant in Kingsport.

The technical portion of the meeting was a tour of Southern Oxygen Co. manufacturing facilities through the courtesy of Howard Snuggs, a director of the Holston Valley Section. Southern Oxygen Co. personnel acted as guides to a very comprehensive and enlightening tour.

The tour was timed so that everyone was able to observe the manufacture and bottling of the gases that are important to the field of welding. The tour consumed approximately two hours and was well enjoyed by all those fortunate enough to be able to participate.

HEAVY STRUCTURES

Nashville—The December 8th meeting of the *Nashville* Section was called to order by Chairman William Regen at 7:30 P.M. at the Biltmore Restaurant.

Thomas J. Dawson, quality control superintendent and chief metallurgist for the Ingalls Shipbuilding Corp., Pascagoula, Miss., presented an illustrated lecture on "Heavy Welded Structures," with particular emphasis on high strength steels and notch strength.

Texas

STUD WELDING

San Antonio—Forty-five members and guests attended the December 5th meeting of the *San Antonio* Section held at Capt. Jim's. The Section was honored to have Percy Pennybacker, past director of District 9, as a guest.

H. Boni of KSM Southwestern,

FOX VALLEY GUEST

Speaker L. M. Petryck (center) discusses point with John Teigen (left) and Gordon Jacklin at November 16 Fox Valley Section meeting

Inc., was the principal speaker using as his subject, "Stud Welding." Mr. Boni presented the history of stud welding from its beginning through the present time. It was interesting to note that stud welding in its beginning in 1942 started with two applications and by 1962 there will be approximately thirty-seven hundred applications. This, in itself, is a tremendous advance in the welding field.

The speaker covered the subjects of welding economy, the advantages of stud welding over manual welding and its limitations. Many specimens were presented, showing its penetrating quality and many applications. Stud welding is accepted as standard procedure for bridge construction, appliances, automobiles and other manufacturing operations, as well as in fabrication.

A very informative question-and-answer period followed the regular program.

Utah

ELECTRON BEAM WELDING

Salt Lake City—The October meeting of the *Salt Lake City* Section was held at Panorama Inn on October 20th. Robert A. Stone of the Air Reduction Sales Co. Special Products Dept. was guest speaker. Mr. Stone spoke on the new electron beam welding process, its possibilities for application and the equipment required.

SHORT ARC WELDING

Salt Lake City—Lynn Hall, engineering service representative for the Linde Co., was guest speaker at the November 17th meeting of the *Salt Lake City* Section held at Panorama Inn. His subject was "Short-arc Welding of Light Gage Steel."

CHRISTMAS PARTY

Salt Lake City—The *Salt Lake City* Section held its annual Christmas party on December 3rd at the Elks Club. Fifty-six members and wives enjoyed a very good dinner and dance.

Wisconsin

NICKEL ELECTRODES

Appleton—The November 16th meeting of the *Fox Valley* Section held at Appleton Elks Club was very well attended. The meeting kicked off with a movie "Green Bay Packer Highlights of 1959" and was followed by an interesting discussion delivered by L. M. Petryck, welding specialist for the International Nickel Co., Inc., New York, N. Y.

In his talk Mr. Petryck covered, in a general manner, the welding of the cast and ductile irons and the metallurgical problems resulting from welding. He also discussed the mechanical properties which should be expected of sound weldments. The oxyacetylene as well as the electric arc welding processes were also covered. He stated that, from the standpoint of the weldment, the oxyacetylene process is superior. However, due to lack of competent oxyactylene welders and for the sake of speed, the electric arc welding process is used far more frequently today. He also stated that the 55% nickel electrode will usually give a higher quality weldment because of the higher iron content which makes the weld analysis more like the analysis of the base metal than when higher nickel content electrodes are used. Further, machineability is not usually affected to a point where it is a factor in the selection between a 55% nickel electrode and one of higher nickel content.

CHRISTMAS DINNER-DANCE

Hollandtown—The *Fox Valley* Section historically sets aside the December meeting to provide the members and their wives with an opportunity to dine and dance at a Christmas party. Always a popular event, ticket sales this year exceeded 200. Wm. T. Hart, the Section's first chairman, was an entertaining master of ceremonies. The food was delicious, and everyone danced until 1:00 A.M. to the music of Harold Janssen and his orchestra. The affair was held at Van Abel's in Hollandtown. The hall and tables

FOX VALLEY MC

Robert Gehrt at microphone during Fox Valley Section annual Christmas dinner-dance on December 10

were gaily decorated and the ladies provided with corsages. A good time was had by all—and now the wives will see that their husbands' dues are paid and permit them to attend the regular technical meetings.

RESISTANCE WELDING APPLICATIONS

Milwaukee—The November dinner meeting of the *Milwaukee* Section was held at the Ambassador Hotel on November 18th. There were 73 members and guests in attendance for the buffet style dinner.

The coffee speaker was H. C. Brockel, who is the Municipal Port Director for the City of Milwaukee The title of his talk was "The World Comes to Milwaukee." Mr. Brockel enumerated a great number of foreign countries which were represented by ships coming into the Port of Milwaukee either to take on or to take off cargo. He explained how the whole Middle West had benefited by Milwaukee being put on the shore of this continent.

John D. Eyestone of Western Electric Co. was the featured speaker. The topic of his presentation was "Resistance Welding Applications at Western Electric, Hawthorne Works." Mr. Eyestone touched upon the past, present, and future types of resistance welding machines used by his company. He emphasized the smallness of parts to be welded so as to meet telephone switching service requirements. The minute parts present many problems in fixturing and designing welding machines to do the job. The use of tape and progressive punching or blanking dies has done much to speed up production and to solve some of these problems. He said his industry designs the parts to a life expectancy of 40 years. The talk was accompanied by slides and many samples were displayed.

NEWS of the industry

ASM Buries Welded Time Capsule for 300 Years

An American Society for Metals time capsule, presented to the organization earlier by A. O. Smith Corp., Milwaukee, Wis., was recently buried for 300 years at the 80-acre site of the new ASM national headquarters in Metals Park near Cleveland, Ohio. The capsule contains documentation of metallurgical progress to date, and is buried alongside a separately enclosed quantity of uranium.

The copper-aluminum container was welded shut at A. O. Smith's Milwaukee, Wis., welding laboratory. L. B. Smith, president of the firm, performed the welding.

Miller Electric Pays Bonus

For the second year in succession, Miller Electric Mfg. Co., Appleton, Wis., announced a 10% of base pay year-end bonus for all employees. This figure includes all overtime worked.

This announcement was made by Niels C. Miller, president of the company at the firm's annual Christmas party held during mid-December.

James F. Lincoln Given Award

James Finney Lincoln (HM), Chairman of the Board of The Lincoln Electric Co., Cleveland, Ohio, was cited for his "outstanding leadership and inspiration in the creation and development of the electric arc welding process and industry." The occasion was the 34th annual meeting of the National Electrical Manufacturers Assn., at which Mr. Lincoln was presented with the coveted James H. McGraw Award Manufacturers Medal established 35 years ago by the late James H. McGraw, former president of the McGraw-Hill Publishing Co., to encourage constructive thinking and action for the advancement of the electrical industry.

Air Reduction Consolidates

All activities of Air Reduction Co., Inc., in the industrial chemical field have been consolidated into a single operating unit, John A. Hill, president, announced recently. The three chemical divisions—Air Reduction Chemical Co., Colton Chemical Co. and National Carbide Co.—have been consolidated into a new division known as Air Reduction Chemical and Carbide Co.

Officers of the new division, Air Reduction Chemical and Carbide Co., are: G. R. Milne, president; B. R. Krashin, vice president—marketing; R. T. Lund, vice president—operating; R. A. Speck, vice president—distribution; J. M. Tinnon, vice president—engineering; F. E. Evers, controller. C. J. Mc Farlin, president of Air Reduction Chemical Co., will join the corporate forward planning group.

Eutectic Reveals Plans for New Metallurgical Center

Eutectic Welding Alloys Corp. recently revealed plans to construct a $2.5 million metallurgical plant and research center, to be begun in 1962 at its World Headquarters in Flushing, N. Y. The announcement was made by Rene D. Wasserman, president and director of research, at a luncheon for civic and industrial leaders marking Eutectic's 20th Anniversary. The ceremonies also included the welding into place

James F. Lincoln

G. R. Milne

RECORD FOR POSTERITY

M. A. Scheil, Director of Metallurgical Research at A. O. Smith Corp., and L. B. Smith (right), president of the Milwaukee manufacturing concern, are shown with ASM time capsule they just welded shut for 300 years

of a metal "cornerstone" for a new 25,000 sq ft administration building now being completed by Eutectic in Flushing, and the introduction of a 20th Anniversary Parade of New Products.

COMING EVENTS

A Calendar of Welding Activity

SNT

Feb. 14-16. Second Annual Symposium on Nondestructive Testing of Aircraft and Missile Components. Gunter Hotel, San Antonio, Texas.

ASM

Feb. 16–17. Albuquerque and Los Alamos Chapters and University of New Mexico. Symposium on "Recent Developments in Materials for Nuclear Applications."

Mar. 20–24. 12th Western Metal Congress and Exposition. Pan-Pacific Auditorium, Los Angeles, Calif.

AWS

Mar. 24-25. Kansas Welding Show. Kansas National Guard Armory, Wichita.

April 17–21. 42nd Annual Meeting, Hotel Commodore, New York, N. Y.

April 18–20. Welding Show, New York Coliseum.

IAA

April 24–25. Convention. Boston, Mass.

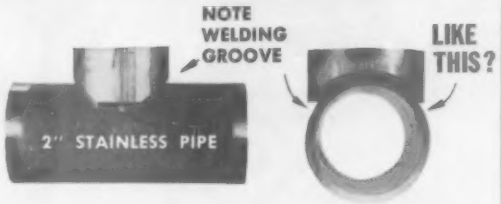
NWSA

May 8–10. Seventeenth Annual Convention, Hotel Commodore, New York, N. Y.

AIIE

May 11–13. 12th Annual National Conference and Convention. Sheraton-Cadillac Hotel, Detroit.

CAN YOU — IN YOUR SHOP — MAKE UP A WELD JOINT?

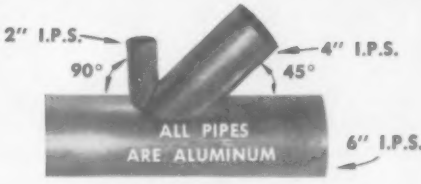


In less than 2 minutes?

CAN YOU THEN WITH NO DIE CHANGE MAKE THIS SET-UP?...

. . . and have both done in less than 4 minutes?

HOW WOULD YOU MAKE THIS ONE?



You could have made all 3 joints shown in *less than 15 minutes* with your

"De Witt Weld Joint Making Unit"!

You should have one! Investigate! "How simple!" one customer said.

Ask for Ed De Witt

Phone me today!
Call me collect!
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My job is to make your job of weld joint preparation easier.

Or . . . write for a sample. (Tell me what joints you make)

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For details, circle No. 13 on Reader Information Card

55,000!

HIGH STANDARDS AND QUALITY ELECTRODES FEATURE CONSTRUCTION OF WORLD'S HIGHEST PRESSURE STEAM GENERATOR.

The Eddystone Station of the Philadelphia Electric Company is a milestone in power station engineering and operating efficiency.

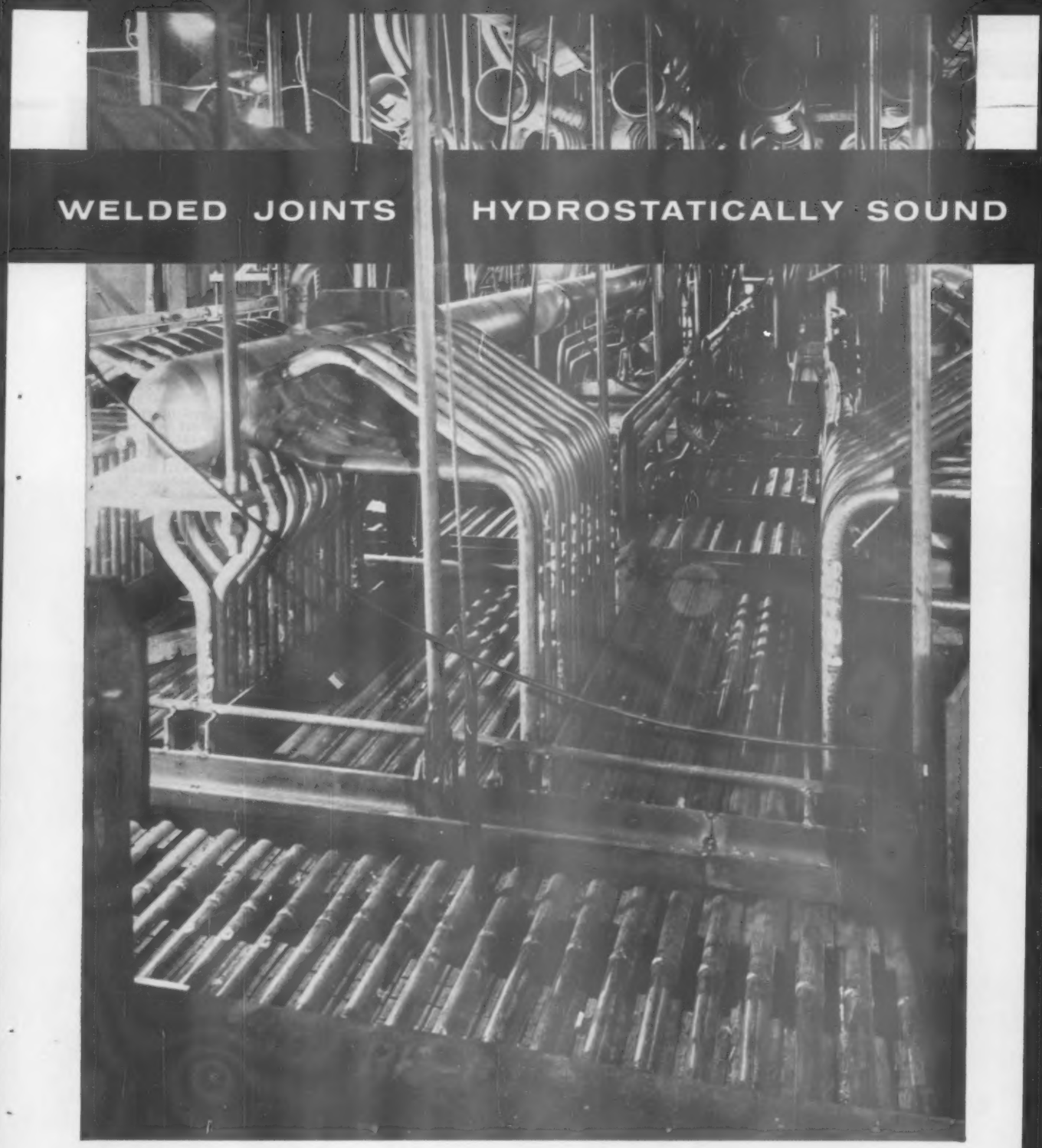
Situated on the banks of the Delaware River south of Philadelphia, Eddystone is the first power station in the world designed to produce steam at the supercritical pressure of 5,000 pounds per sq. in. and a temperature of 1200° F. This breakthrough in the commercial generation of electricity is expected to set a new world's record for power station efficiency by producing a kilowatt hour from 2/3 pound of coal.

55,000 welds were used to fabricate the hundreds of miles of tubing and piping used in the construction of the steam generating unit. Approximately 25,000 of these were field welds made at the construction site. The extreme operating pressure and temperature necessarily required unusually high weld metal quality and reliability from the electrodes selected. For the field welds, Combustion Engineering, designer and manufacturer of Eddystone's No. 1 boiler, specified Arcaloy types 316 and 347 stainless steel electrodes for the chromium-nickel material, Atom·Arc 8018CM and 9018CM iron powder low hydrogen electrodes for the chrome-moly grades and Atom·Arc 7018Mo for the carbon-moly grades. Continuous visual inspection was conducted as all welding proceeded. Dye penetrant and X-ray inspection of welds were used throughout the erection of the boiler. When the boiler had been completely welded, it was hydrostatically tested at 8,000 psi. pressure. All of these tests and inspections failed to show one defective or leaking field weld.

These dynamic results mirror the experiences of many leading fabricators throughout the country. Like Combustion Engineering, they have proven conclusively that X-ray quality weld metal of Alloy Rods Company electrodes increases the efficiency of their welding operations. They have learned from experience—you can profit from their experience. Specifying your electrode requirements from our extensive line of quality alloy arc welding electrodes is the one sure guarantee of satisfaction. Alloy Rods Company, York 3, Pennsylvania.

The steam producing heart of the station is a C-E Sulzer Monotube Steam Generator, designed and manufactured by Combustion Engineering. This unit is 12 stories high, 100 feet across, and 75 feet from front to back. 170 miles of all-welded tubing and piping, low-chromium and chromium-nickel material, went into the unit's fabrication.

For details, circle No. 14 on Reader Information Card



WELDED JOINTS HYDROSTATICALLY SOUND

ALLOY RODS COMPANY

YORK, PENNSYLVANIA

SALES OFFICES & WAREHOUSES; BOSTON, NEWARK, PHILADELPHIA, PITTSBURGH, BIRMINGHAM, CHICAGO, SAN FRANCISCO & EL SEGUNDO, CALIF.—DISTRIBUTORS IN ALL OTHER PRINCIPAL CITIES

TWENTY YEARS OF LEADERSHIP IN THE DEVELOPMENT OF QUALITY ALLOY ARC WELDING ELECTRODES

For details, circle No. 14 on Reader Information Card

Welding Machine Nears Diamond Anniversary

What is thought to be the oldest piece of resistance welding equipment still in use in this country is located at the Rempe Co., Chicago, Ill. The unit, made in 1889 and used exclusively for 70 years to weld pipe coils for heating and refrigerating applications, is a floor-mounted butt welder, manually controlled and rated at 25 kva.

Rempe Co. bought the machine from Thomson Electric Welder Co. of Lynn, Mass., its designer and manufacturer, in 1896. For the most part, techniques for operating the machine have remained consistent over the years. Sections of black iron pipe—in 1- or 2-in. diam and standard or extra-heavy weights—are cleaned at the ends; edges are uniformly prepared and the section then put in the dies and clamped. Clamps are actuated through air valves—now of the lever type—in the line. The right-hand platen is moved with a relatively large hand wheel geared through a worm and ratchet.

John Schaeffer, after 52 years of operating this piece of equipment, can still produce quality welds consistently. Officially, Mr. Schaeffer retired in 1959, but Rempe still calls on him occasionally to weld up sections of black iron pipe.

Butt-welding machine at Rempe Co. has been used on an estimated billion feet of pipe since 1896

John Schaeffer, operator of the Rempe Co. machine for 52 years

NCG Supplies Plumbing Training Center

A new plumbing and pipe fitting apprentice training center described as the most modern in the country was dedicated at Norfolk, Va. It is a result of a cooperative effort by labor, management and other groups, according to R. L. Ballentine, apprentice representative, Bureau of Apprenticeship and Training, U. S. Dept. of Labor.

City councilmen and representatives of the United Association of Journeyman Plumbers and Steamfitters and the Joint Apprenticeship Committee participated in ceremonies which included a preview of electric welding and gas welding and cutting equipment supplied by the National Cylinder Gas Div., Chemetron Corp., through the Henry Walke Co. The center represents an $18,000 investment in training mechanisms. City Councilman Paul Schweitzer said the plumbing and pipe fitting center served as a model of what could be done in other trades, and should help bring new industry into the area.

Arcrods Expands Cleveland Plant

Work has begun on the expansion of the Cleveland, Ohio, facility of Arcrods Co. was recently announced by W. E. Brainard, president, at Sparrows Point, Md. Arcrods produces welding electrodes and wires for shipbuilding, construction, general metalworking and other industrial applications.

The 50,400 sq ft addition at 4437 E. 49th St., Cuyahoga Heights, will cost approximately $800,000 and will be used for wire drawing operations. The new facilities will make steel inventory more flexible and permit improved service through stockpiling.

Scheduled for completion early this year, the new facility is being constructed by the Albert M. Higley Co. of Cleveland. The Cleveland plant was built in 1939 on a 7.8 acre site and has undergone several expansions since that time, the most recent in 1952. The plant is under the supervision of R. J. Hewett, with H. C. Felver functioning as superintendent of the new wire mill addition.

BATEMAN
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IRON WORKER

THE ONLY IRON WORKER OF ITS KIND ON THE MARKET TODAY

No Grinding Necessary After Cut. One Stroke Cycle Clutch Operated by Hand or Foot.

The Bateman "Bantam" cuts 2" x 2" x ¼" angles and ¼" x 4" flats. Standard punches will fit this machine. The Coper will cope 1¼" through ⅛" material. It will punch ½" hole through ¼" material. With the clutch open, the Bantam will make 44 strokes per minute. It is made of high-grade cast iron, with the clutch, pin and dog made of hardened steel. The blades are made with tool steel. It is powered with a fly wheel and gear drive, and uses a small ¾ hp motor, 1750 rpm.

Bateman Bantam with punch....$575.00
Shipping weight—750 lbs.
Bateman Shear.....$494.00
Shipping weight—715 lbs.

BATEMAN FOUNDRY & MACHINE
MINERAL WELLS, TEXAS

For details, circle No. 15 on Reader Information Card

Welding Electrode Plant Expansion

To keep pace with its growing welding electrode business, Marquette Manufacturing Co., Minneapolis, Minn., announces a $500,000 expansion of productive facilities, including a new plant of 21,000 sq ft and a 6000 sq ft addition to its existing welding electrode plant. Dr. Frank W. Scott, plant manager, states that this will double the firm's capacity.

Construction of the new plant was scheduled to start January 1st and it is expected that the new facility will be in operation by July 1, 1961. The building will house new automatic wire drawing equipment manufactured in Sweden. Mill obtained hot rolled rods will be automatically drawn to wire sizes from $^1/_{16}$ to $^1/_4$ in. for use in the manufacture of welding electrodes. It is expected that by drawing its own wire the company will save over $100,000 annually in production costs.

The addition to the present plant was expected to be complete by December 1st.

For details, circle No. 16 on Reader Information Card→

See us at Booth 619 at Welding Show, N. Y. Coliseum, April 18-20

Biggest U. S.-built ship welded with M&T Murex electrodes

The *Princess Sophie*, built by Bethlehem Steel Company, has the latest electronics, a foam fire-protection system, a fully equipped hospital, air-conditioned quarters—all making this one of the safest and most luxurious supertankers ever built. When loaded, it has a greater displacement (100,000 tons) than any passenger or military ship afloat. In building the Princess Sophie, welding was with Murex electrodes—products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

development of a highly-advanced, new process for producing hard metals.

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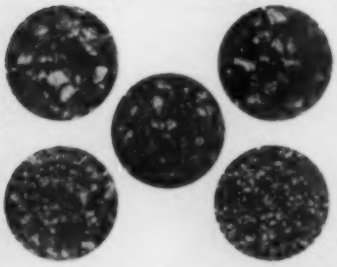
granular tungsten carbide

the leader of CleMet Products' new line of hard metals



5 uniform grain sizes of improved toughness and high strength

- Maximum abrasion-resistance
- For application in the petroleum, agriculture, construction and mining industries whose equipment is subject to extremely rugged, abrasive duty.

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Foreign Film Award

The Antwerp Film Festival Committee announced the award of its highest motion picture honor, the Diplome De Merite Exceptionnel, to a Louisville, Ky., company, Vogue Film Productions, for the industrial motion picture, "Welding Aluminum—Different, Not Difficult." A separate award was presented to the film's sponsor, Reynolds Metals Co. of Richmond, Va.

According to Hal Vinson, president of Vogue, the festival is held each year by the Ministry of Labour, Kingdom of Belgium, to gather, study and compare industrial films. The 1960 competition included 450 films from 30 countries.

"Welding Aluminum—Different, Not Difficult" explains how aluminum differs from other metals and demonstrates the production techniques used in joining aluminum. The film is in full color on 16-mm film and is a little over 33 min in length.

The film is available for viewing by audiences interested in aluminum fabrication and welding. It may be obtained by writing to George Birdsall, Director of Editorial Services, Reynolds Metals Co., Richmond, Va.

Chemetron Acquires Detroit Company

The Chemetron Corp. of Chicago, Ill., has acquired, for cash, Northwest Chemical Co., Detroit, Mich., manufacturer of chemicals widely used in the metalworking industry. Products of the 28-year-old Detroit company include metal cleaners of immersion, electrolytic and spray types; acid addition agents; phosphate coatings; paint strippers; and other chemicals and compounds for conditioning ferrous and nonferrous metals before plating, etching, welding, anodizing, priming, enameling or painting.

Northwest Chemical Co.'s plant and offices will remain at 9310 Roselawn, Detroit. Harold J. McCracken, B. F. Lewis and Helen M. Morell are the officers and founders of the firm and will continue in charge of operations.

Northwest Chemical Co. becomes a part of the Chemical Products Div. of Chemetron. Other units of the division are Dunham Chemical Co., Crestwood Chemicals, Girdler Catalysts, Holland Color and Chemical Co., Rock Hill Research Laboratory, Specific Pharmaceuticals and Charles J. Weigel, Inc.

Engineers Joint Council Elections

James N. Landis, Vice-President of the Bechtel Corp. of San Francisco, was recently elected President of Engineers Joint Council at a meeting of the Council's Board of Directors. Engineers Joint Council is a national federation of 21 engineering societies organized to advance national and human welfare by promoting cooperation among the various specialties of engineering.

Landis, who is past president and present Council member of the American Society of Mechanical Engineers, succeeds Augustus B. Kinzel, Vice President of Union Carbide, who headed EJC for the past year.

The Board reelected George E. Holbrook as Vice-President. Holbrook, Past President of the American Institute of Chemical Engineers and present Vice President of E. I. du Pont de Nemours & Co., Inc., served in that post during 1960.

RWMA Reports Excellent October

Monthly shipments of resistance welding equipment were well in excess of $2 million, as revealed by recently compiled statistics of the Resistance Welder Manufacturers' Assn. October was the ninth consecutive month in which shipments exceeded this mark.

For the first ten months of 1960, shipments were 18½% ahead of the similar period in 1959, even though October dropped behind the September 1960 figure.

New business increased considerably in October over September, but for the year was slightly behind the ten months of 1959. Backlogs were reported at better than $8½ million at the end of October.

Mobilweld Sold

Mobilweld, Inc., Chicago, Ill., recently announced that a majority interest in the company has been acquired by Poor & Co., Chicago, a leading supplier to railroads in this country and abroad.

Mobilweld is the inventor and developer of a rail welding process that can be moved from site to site or operated in a fixed location. Officials said the service is designed to meet the railroad industry's present unfilled need for welding on location, and may be used also for industrial and defense requirements.

Poor & Co. stated that the acquisition is a "natural complement" to the other services the company is rendering to the railroad industry.

For details, circle No. 18 on Reader Information Card →

See us at Booth 619 at Welding Show, N. Y. Coliseum, April 18-20

World's biggest power shovel welded with M&T Murex electrodes

Picture this 6,588,000 lb. giant on the 50-yard line of a football field. It could dig a 65 cu. yd. dipper-full in one end zone, lift it 140 feet high, swing its 170-ft. boom and pile the 100 ton load on a 12-story building in the opposite end zone. For many of the shovel's most important weldments, the builder, Marion Power Shovel Co., put its trust in M&T Murex electrodes — products of METAL & THERMIT CORPORATION, General Offices: Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

Linde Distributors Attend Seminar

Representatives from a dozen Linde distributorships recently attended a distribution and safety training seminar at Linde's Elizabeth, N. J., oxygen plant. C. J. Roth, superintendent of the plant conducted the general session in which new techniques and safe practices for the handling, charging, transporting and storage of liquefied and high pressure gases were thoroughly explained. The program was developed to provide distributors with a better knowledge of gas and liquid distribution.

Representatives from Linde distributorships listen to explanation of new liquid nitrogen trailer as part of a program which distributors attended to learn the handling techniques of gas and liquid distribution equipment

New Canadian Company

A new Canadian company, supplying the metal working industry with metal-removal torches and supplies, has been formed. Called Arcair of Canada, Ltd., it is located at 805 Davenport Rd., Toronto.

The new company will serve as sales and distribution headquarters in Canada for Arcair torches and carbon electrodes. President of Arcair of Canada, Ltd., is Myron Stepath. Don Fraser is Field Sales Representative, and Mrs. Ruth Flauder is Office Manager.

Symposium on Welding in Shipbuilding

The Royal Institution of Naval Architects, the Institution of Engineers and Shipbuilders in Scotland and the North East Coast Institution of Engineers and Shipbuilders have agreed to cooperate with the Institute of Welding in a joint symposium on welding in shipbuilding to be held in London in October and November 1961. The Joint Committee invites offers of papers on: The Structural Design of Welded Hulls, The Building of Welded Ships, Shipyard Layout for Welded Shipbuilding, Automatic Welding in Shipbuilding, Materials Handling, Welded Joints in Thick Mild Steel, The Use of High Yield Point Steels in Welded Ship Construction, Aluminium Alloys for Welded Ship Construction, Nondestructive Testing of Ship Welds and Training and Testing of Ship Welders.

All papers accepted by the Joint Organizing Committee will be preprinted and subsequently published with the Discussion in a volume of *Proceedings*. Manuscripts (complete with illustrations) will be required by Apr. 1, 1961. The preferred length of papers is 2000 to 3000 words.

Offers of papers, which should include a synopsis of not more than 200 words, should be addressed to The Secretary, Joint Symposium Committee, The Institute of Welding, 54 Princes Gate, Exhibition Road, London, S. W. 7.

Budd Name Change in Canada

The name of the Budd Co. Canadian subsidiary has been changed from Tatnall Measuring & Nuclear Systems Ltd. to Budd Instruments Ltd. according to a recent announcement made by Dr. John H. Buck, president of Budd Instruments Ltd. and vice president and general manager of the Instruments Div., of the Budd Co.

The Canadian offices have been moved from 46 Hollinger Rd., Toronto, to 170 Donway West, Don Mills, Ontario.

Glenn Pacific Changes Name

Glenn Pacific Power Supply Corp., manufacturers of welding and industrial power supplies, located at 703—37th Ave., Oakland, Calif., will henceforth be known as the Glenn Pacific Corp.

In making the announcement, George G. Glenn, president, stressed that the change involves only the corporate name and that personnel, policies, products and distribution will remain the same.

Goodrich Appointment

Goodrich Welding Equipment Corp., Hudsonville, Mich., recently announced the appointment of Arke Research and Development Co. of Northridge, Calif., as the Western manager and consultant for Goodrich.

This move by Goodrich will provide comprehensive support for all types of welding applications, equipment, and processes. Related jigs, fixtures and handling devices will also supplement the regional activity and provide users with rocket, missile, and aircraft welding or handling problems to contact well-experienced personnel in those fields.

Who said: "Un-weldable?"

Before you call it "un-weldable" check it out on the NRC Electron Beam Welder. Problems posed by reactive metals, dissimilar materials, heat sensitivity, and unusual geometry are being solved daily.

•Tungsten, tantalum, columbium, zirconium, etc. are welded free of contamination and porosity • Finish machined parts are joined without distortion • Sensitive instruments are evacuated and sealed • Precision welds are made at the bottom of a 1/16" slot or between two surfaces meeting at an acute angle • Depth/width ratios greater than 4/1 are attained.

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For details, circle No. 20 on Reader Information Card →

See us at Booth 619 at Welding Show, N. Y. Coliseum, April 18-20

World's tallest structure relies on M&T Murex electrodes

Almost 1000 tons of steel stretching 1676 feet into the sky! This new television transmission tower for KFVS-TV, Cape Girardeau, Missouri, is the tallest structure man has ever built. It's 204 feet taller than the Empire State Building, has solid steel legs up to 7½" in diameter, can withstand winds of over 100 mph. In welding the 30-ft sections of this triangular tower of strength, Dresser-Ideco Company put its trust in M&T Murex electrodes... products of METAL & THERMIT CORPORATION, Rahway, New Jersey.

M&T MUREX
PRODUCTS FOR BETTER WELDING

PERSONNEL

Brown Named President

The Board of Directors of National Welding Equipment Co., San Francisco, Calif., has elected Richard K. Brown AWS as president following the retirement of Ernest L. Mathy, who will continue in an advisory capacity.

Mr. Brown, a resident of Oakland, Calif., has been associated with the firm for the past decade, serving in the capacities of salesman, sales manager and more recently as vice president and general manager. National Welding is celebrating its 50th anniversary, and contemplates a sizable expansion program within the near future.

Bowling Named by Airco

Van Dorn Bowling, Jr., AWS has been appointed assistant manager of distributor sales for Air Reduction Sales Co., Houston district, it was announced by H. C. Wallace, regional sales manager of Airco's southern region.

In this position, Mr. Bowling is responsible for liaison and guidance of distributor activities for Airco's Houston district, located at 3603 Cherry St., Houston. A graduate of the University of Louisville, Louisville, Ky., Mr. Bowling has been associated with Airco since 1957. He was employed in the Louisville and Charlotte districts before taking over his present duties.

Mr. Bowling is former director and membership chairman of Holston Valley Section of the AMERICAN WELDING SOCIETY. He now resides at 4522 Wedgewood, Houston.

Williams Advances

E. R. Walsh, III, vice president in charge of sales, Alloy Rods Co., York, Pa., recently announced the appointment of J. J. Williams AWS to the post of assistant vice president in charge of sales. Williams was formerly eastern regional manager controlling sales and distribution in the New England and Middle Atlantic states.

Arcos Names Anderson

Robert W. Anderson AWS has been appointed New England district sales manager of Arcos Corp., Philadelphia, Pa. James E. Brickett, general sales manager, said in announcing the appointment that Anderson will handle the company's full line of welding rods and wire, wire feed units, electrodes, fluxes and accessories.

Anderson's headquarters will be in Boston, where he officially took up his new duties on December 1st. He has been a district salesman at Arcos' district sales headquarters in Chicago. Before that he was a salesman in the Boston office where he is now returning as district manager.

Klasson Named Supervisor

George A. Klasson AWS has been named Supervisor of the Plasma Flame Cutter Dept. at Thermal Dynamics Corp., Lebanon,

R. W. Anderson

Van Dorn Bowling, Jr.

G. A. Klasson

R. K. Brown

J. J. Williams

D. L. Heisler

N. H. He was formerly sales manager for Okiva, Inc., Cincinnati, Ohio, welding equipment distributors. After several years of development, Thermal Dynamics will soon market a new high-speed plasma cutter for metals of all types, from aluminum to tungsten. Operating at temperatures up to 60,000° F, the new torch combines tremendous cutting speed with lower operating cost.

Loveless Becomes Plant Manager

Gordon R. Loveless AWS, manager of the Chicago Bridge & Iron Co. Salt Lake City plant since 1957, has been appointed manager of CB&I's major eastern plant at Greenville, Pa. He assumed his new duties on Jan. 16, 1961. Succeeding Mr. Loveless is Alfred J. Larson, formerly of Salt Lake City, who presently is assigned to the firm's Greenville plant.

Mr. Loveless left for Pennsylvania after spending 12 years at Salt Lake City where he joined the company in 1948. Mr. Larson joined in 1951 after graduation from the University of Utah.

Vickers Appoints Heisler

The appointment of Douglas L. Heisler as Director of Purchasing, Vickers, Inc., Div. of Sperry Rand Corp., Detroit, Mich., has been announced by R. M. McCabe, vice president for Purchasing.

Prior to joining Vickers, Mr. Heisler was Corporate Procurement Manager of the Whirlpool Corp. Earlier assignments included five years with Worthington Corp., the last year as purchasing manager of its Harrison Div., and five years with Mack Manufacturing Corp.

Blodget Appointed Vice President

A. S. Blodget, Jr., has been appointed regional vice president of the Air Reduction Sales Co. midwestern region. As regional vice president Mr. Blodget is responsible for the sale and distribution of all Airco products marketed in the midwest area, which includes the districts of Chicago, Milwaukee, Minneapolis, Bettendorf, Kansas City, St. Louis and Detroit. Regional headquarters are located in Chicago. Mr. Blodget succeeds D. D. Spoor, who is retiring.

Mr. Blodget joined Air Reduction in 1938 shortly after receiving an A.B. degree in government from Harvard University.

Lincoln Promotes Engineers

The Lincoln Electric Co., Cleveland, Ohio, announces the transfer of Ronald C. Pierce AWS from Savannah, Ga., to their Mobile, Ala., office.

James T. Hart and Richard K. Lore, after completing a one year training course at the factory, have been appointed to The Lincoln Co. staff of field engineers and assigned to the Memphis, Tenn., and Atlanta, Ga., offices, respectively.

Bertram Named

John J. Bertram, Jr., has been appointed manager, Advertising and Sales Promotion, of American Hard Rubber Co., div. of Amerace Corp., Butler, N. J. His appointment was announced recently by J. P. Coughlin AWS, the divisions's vice president —Sales.

Mr. Bertram had formerly been assistant advertising manager of Gaylord Container Div., Crown Zellerbach Corp., St. Louis, Mo. In his new position he will direct advertising and sales promotion activities not only at American Hard Rubber but also at Amerace's other divisions.

LENCO, INC.
350 WEST ADAMS ST., JACKSON, MISSOURI
For details, circle No. 21 on Reader Information Card

Largest Shovel

Tallest Structure

Biggest Tanker

Here are three fine achievements with steel . . . shovel, tower, ship . . . each a leader, each welded with M&T Murex electrodes.

Dozens of demanding jobs like these . . . and hundreds of everyday applications . . . have established the Murex reputation.

When you think of electrodes, think of your M&T Murex representative—a specialist with a wealth of background and training to put at your service. Or look into the Murex Electrode Selector for a complete listing of over 1000 Murex types and sizes. Copies available from: METAL & THERMIT CORP., Advertising Dept., Rahway, N. J.

M-T MUREX welding products

METAL & THERMIT CORPORATION
General Offices: Rahway, New Jersey
Visit Booth 619 at Welding Show, N.Y. Coliseum
For details, circle No. 22 on Reader Information Card

Westrum Named Sales Manager

C. W. Onan, president, Onan Division of Studebaker-Packard Corp., electric generator manufacturer in Minneapolis, Minn., announced the recent appointment of Robert L. Westrum AWS as Sales Manager of a newly created OEM sales department.

"The rapidly growing importance of including original equipment manufacturers in our over-all marketing picture dictated the establishment of a separate OEM sales department," Onan said.

R. L. Westrum

C. C. Hand

Bob Westrum, an E.E. graduate from the University of Minnesota, joined Onan in 1950. For the past year he has been in charge of OEM accounts, until now a division of the company's Special Products sales department.

Blodgett Appointed General Manager

E. J. Brady, president, Alloy Rods Co., York, Pa., recently announced the appointment of F. L. Blodgett AWS to the post of general manager of the company's Hard Surfacing Products Division. Prior to this appointment, Mr. Blodgett was general sales manager for the company.

Herrick Names Sales Manager

Willard W. (Bill) Wakefield has been named sales manager of the C. B. Herrick Mfg. Corp., Cleveland, Ohio, according to an announcement by Clayton Herrick AWS, president of the company. Wakefield has been with Herrick for a period of eight years, the past five acting as chief engineer. He has been in the welding industry since 1935.

In his new position, Wakefield will be working with Herrick dealers in the United States, Canada and Mexico.

Allis-Chalmers Appointments

Appointment of Kenneth J. Martin as assistant foreman, electrical maintenance department, and of Charles E. Tewes as assistant foreman, materials department, at the West Allis Works has been announced by Allis-Chalmers Manufacturing Co., Milwaukee, Wis.

Both men are graduate electrical engineers, Martin of the University of Wisconsin and Tewes of Virginia Military Institute. They recently completed Allis-Chalmers training course for graduate engineers.

Hand and Johnson Become District Managers

F. L. Blodgett, general manager of the Hard Surfacing Div., Alloy Rods Co., York, Pa., recently announced the appointment of C. C. Hand and M. L. Johnson AWS as district managers. Mr. Hand will headquarter at the Alloy Rods branch office in Pittsburgh, Pa. Mr Johnson will cover the Western states from El Segundo, Calif.

Pitt Becomes Vice President

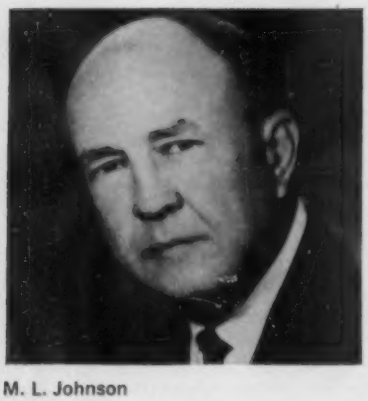
Paul A. Pitt was elected vice president—engineering of Solar Aircraft Co., a subsidiary of International Harvester Co., Herbert Kunzel, Solar president, announced recently.

In his new position, Pitt heads Solar's engineering and research activities. At the same time, Sumner Alpert was named manager of a new division which includes Solar's aerospace, ground support and industrial products, with responsibility for sales and project engineering in these areas.

Baltzegar Named to Top European Post

Cecil Baltzegar has been appointed European operations manager for Omark Industries, Ted Smith, Omark export manager, announced this week. Baltzegar will supervise Omark marketing in Europe, concentrating his initial activities in Scandinavia, the United Kingdom and Germany.

Baltzegar, who was market research manager prior to his new assignment, has been with Omark since 1953. He previously served as assistant to the Oregon Saw Chain Division sales manager and as market research analyst. He is a graduate of the U. S. Merchant Marine Academy.

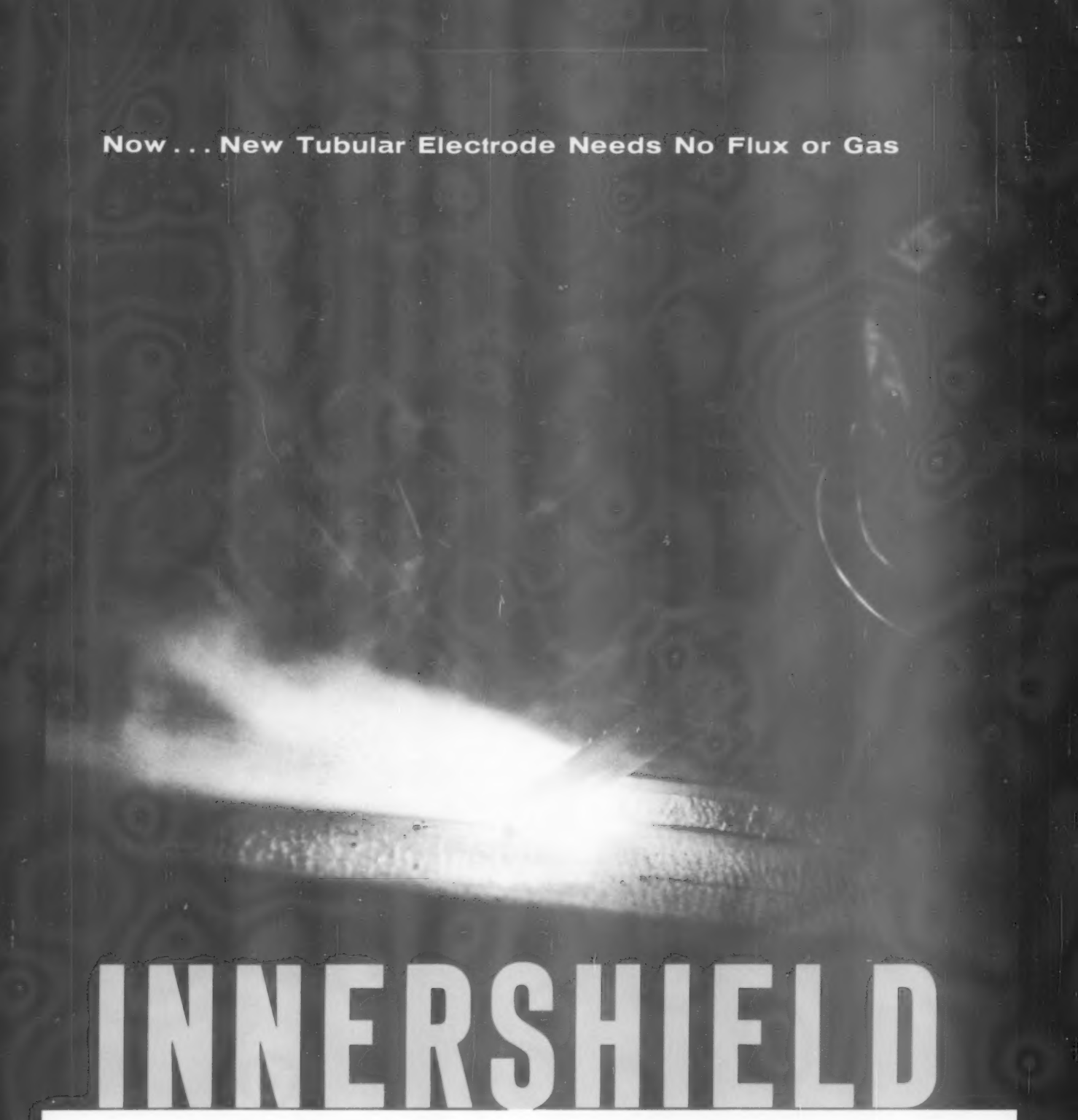


M. L. Johnson

F. L. Blodgett

W. W. Wakefield

For details, circle No. 23 on Reader Information Card →



Now . . . New Tubular Electrode Needs No Flux or Gas

INNERSHIELD

Lincoln's dramatic new welding process–Innershield–uses a special tubular electrode containing all necessary ingredients for welding–filler metal, arc shielding, deoxidizers, fluxes. Needs no CO_2, Argon or granular flux. Two new welders use it–a full-automatic and a semi-automatic called Squirt.

Welding railroad car center sills is easy, fast. The highly efficient, dense and chemically inert conical arc shield is virtually impenetrable by the surrounding air. Welds are sound, stronger than base metal. Visible arc lets operator follow joint easily. Speeds up to 50 ipm possible.

Innershield Squirt is ideal for short, intermittent, single-pass welding on parts such as these building trusses. Innershield electrodes bridge gaps caused by poor fit-up; medium penetration avoids burn-through. Excellent for diversified job shop operations.

THIS IS INNERSHIELD ON THE JOB

☐ I'd like to see Innershield Squirt demonstrated. I understand there is no obligation.

☐ Send Innershield Bulletin 5300.1

Name_____ Title_____

Company_____

Street & No._____

City_____ Zone____ State_____

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Cleveland, Ohio

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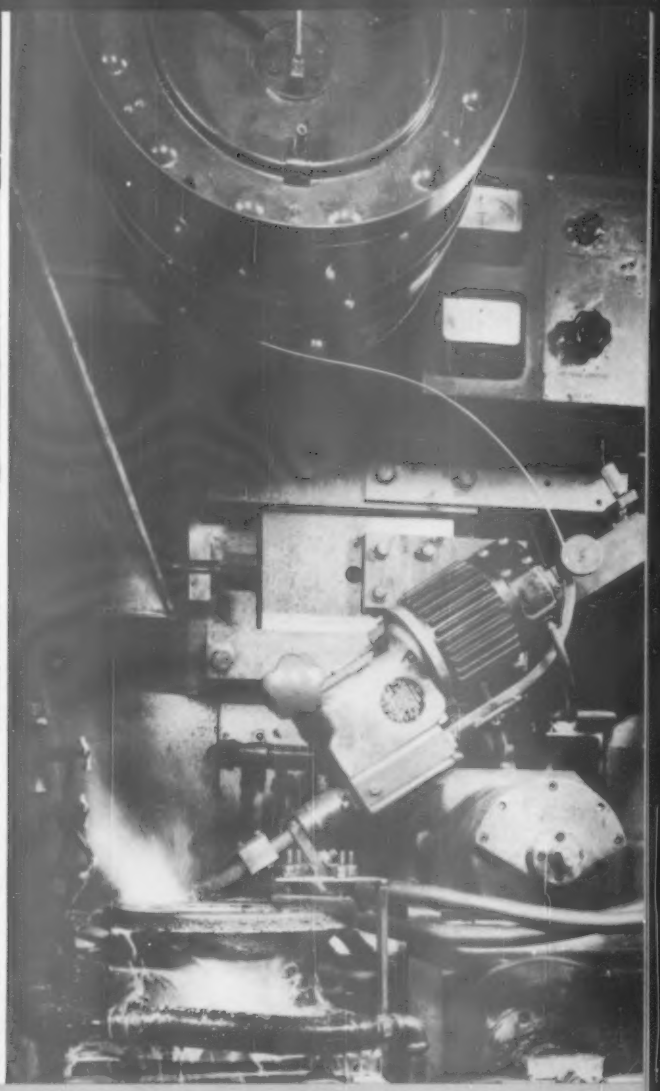
The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland 17, Ohio

Because Innershield Squirt is flexible, easy to use, it replaces manual methods for welding small parts set up in jigs and fixtures. On this job, it increased welding speed by 150%, decreased slag cleaning time, and significantly reduced cost of finished parts.



Here, full-automatic Innershield makes continuous butt weld on 4-inch tubing at 120 ipm. Special electrode eliminates flux used in submerged arc process as well as manifold and piping systems needed for inert gas process. Reduces inventories, purchasing problems, storage space required.

Innershield Squirt is incomparably faster than manual welding both in deposit rate and arc speed. Deposition efficiency is an excellent 85% as contrasted with about 65% for hand welding, 50% for submerged arc. And because there's no stopping to replace electrodes, operating factor is extremely high.

Innershield Squirt is easy to use, too. Even an amateur can pick up the gun and turn out professional welds in ten minutes. We've illustrated (above) a few of the applications where Innershield Squirt is already on the job stepping up production, cutting costs . . . in the job shop as well as on high volume production lines.

See Innershield At Work

Somewhere near you there's probably a Squirt unit at work boosting production, cutting costs. Why not have your Lincoln Field Engineer show it to you? Send in the attached postcard today. And, for a complete description of the Innershield process, available electrodes and both semi-automatic Squirt or full-automatic equipment, ask for your copy of Bulletin 5300.1.

HERE'S THE GUN THAT LETS AN AMATEUR TURN PRO

Pull the trigger, strike the arc, and you're welding faster than ever before. This gun, made of tough molded plastic, needs no water cooling, is light in weight, and is easy to handle. You have to try it to believe how easy it is to make tough, sound welds . . . fast!

MN-1—RUGGED, COMPACT INNERSHIELD SQUIRT WELDER

Here's a compact, sturdy unit designed and built to hold up under rough on-site conditions. It's not finicky. Put it to work in your shop, shipyard or production line, now! Comes complete with wire feed mechanism, wire reel, input and output cables, gun and controls.

LINCOLN WELDERS

THE LINCOLN ELECTRIC COMPANY
22801 St. Clair Avenue
Cleveland 17, Ohio

WELDING SPECIALIST

Practical, competent Welding Specialist with minimum of 10 years experience in fusion welding. Prefer man who has been a welder with experience in welding development work.

Job will be concerned with fusion welding including normal metallic arc, automatic and semi-automatic submerged arc, tungsten inert gas, CO_2 and Heliarc welding. Materials include mild steels, low alloys, stainless steels and aluminum. Products are mid-range in size with majority ranging from 5 to 500 pounds.

This is primarily a staff position, with close coordination with plant. Man will be expected to give welding instructions, develop new techniques, advise on welding design, and general consultation on plant problems. Submit resumes to Personnel Manager.

DRESSER MANUFACTURING DIVISION
BRADFORD, PA.

ONE OF THE DRESSER INDUSTRIES

Matheson Honored

Wilfred G. Matheson, manager of incandescent lamp research for Sylvania Lighting Products, a division of Sylvania Electric Products, Inc., was elected to the Committee of Honor for the 1961 meeting of the French Vacuum Society in Paris, France. Sylvania is a subsidiary of General Telephone & Electronics Corp.

Mr. Matheson served for the past year as president of the American Vacuum Society, during which time there has been a 15% increase in the world-wide membership of this organization. During the past year, a 20% larger technical program was developed with the result that 72 papers were presented in a three day program recently in Cleveland, Ohio.

The author of several technical papers in his field, Mr. Matheson has also represented Sylvania as one of the 12 founding members of the American Vacuum Society. A member of the Illuminating Engineering Society, Mr. Matheson is also a member of the American Institute of Electrical Engineers, the International Vacuum Society and the American Society for Testing Materials.

'Partner wanted for fabricating shop, specializing in stainless and alloy materials for pressure vessels, tanks and equipment for food and chemical industries. Must be experienced in job shop and production operations, also have ability in sales or accounting. Investment required $25,000.00 to $50,000.00. Chicago area.

Write Box No. **V-397**

Tate Made Representative

Jackson Products, Warren, Mich., producers of arc welding and safety accessories, announces an expansion of their Pacific coast sales force. Kenneth C. Tate, formerly with Aerojet Corp., has been appointed Pacific Northwest regional representative with headquarters in Portland. The southern part of the Pacific coast area will continue to be served by George Sloan.

Tate, a former West Virginian, comes to his job with welding and sales experience gained both in the United States and in Latin America. His appointment reflects the continuing industrial growth of the Pacific Northwest, and the increased demand for the arc welding and safety accessories manufactured by Jackson Products.

Siebert Named Manager

The appointment of Carl J. Siebert, Jr., as general sales manager has been announced by Charles N. Aronson, President of Aronson Machine, Co., Inc., Arcade, N. Y. Mr. Siebert's broad experience in industrial marketing is expected to make a timely contribution to the rapidly expanding markets of Aronson Positioners.

Aronson Machine Co., Inc., manufacturer of welding positioners of which there are now over 400 different models, was founded in 1945.

Farmer Advances

W. L. "Len" Farmer, Regional Manager of the RegO Div., Bastian-Blessing Co., Chicago, Ill., will now add supervisory responsibility over the Kentucky territory. Under Farmer, George A. Workman will be District Sales Manager for Kentucky, Michigan, Indiana and Western Ohio.

WELDING ENGINEER

Mechanical Engineering graduate or equivalent. To write welding procedures and handle training and qualification of welders. Primary experience must be in fusion welding including manual, submerged arc and inert gas shielded methods. Will work in carbon, stainless, nickel alloys, chromesteels, titanium, etc.

NOOTER CORPORATION
Personnel Director
1400 South Second Street
Box 451, St. Louis 66, Mo.

The Kentucky territory was formerly covered by Alfred T. Rider who has moved to St. Louis to handle much of the area which was handled by the late Harry Kaye.

OBITUARY

L. F. Vonier

L. F. Vonier, veteran A. O. Smith Corp., welding executive, died recently in Milwaukee, Wis.

Vonier joined the firm's Welding Products Div. in 1937 as general sales manager. In recent years he was a divisional sales consultant.

METALLURGICAL ENGINEER

The Chemstrand Corporation's nylon manufacturing plant at Pensacola, Florida, is seeking a graduate engineer to assist the chief metallurgist in shop problems related to materials selection, welding and heat treatment. Experience with chemical processing equipment desired.

Excellent working conditions and benefit programs. Attractive community life and living conditions in Gulf Coast location.

Send resume of academic training and experience to:

Manager
Employment-Recruitment
Box P4
The Chemstrand Corporation
Decatur, Alabama

New Literature

Color Movie on Industrial Gases and Welding

The Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., has just issued a 16-mm film titled "Industrial Gases and Shielded Arc Welding," featuring recently developed welding equipment and techniques. Filmed in full color and sound, the 27-min production correlates the story of industrial gases—oxygen, nitrogen, hydrogen, argon and carbon dioxide—with welding applications. An outline of the important role played by these gases, from their use in steelmaking to adding color to Times Square, is given briefly in the opening scenes.

The major portion of the film features the uses of these gases in gas-shielded arc welding equipment. Through the eye of the ultra high-speed camera, multiple high-speed weldments and cutting operations are vividly reproduced.

Also captured on film are examples of economical and automatic production in the automotive field with Aircomatic equipment; expert fusion welds on aluminum with Heliweld and precise weldments on one side, all-position work with Aircospot welding equipment.

Prints of the film may be obtained on loan and without charge by contacting local representatives of the Air Reduction Sales Co., listed in the telephone directory.

Projection Welding

A new 20-page brochure, *Projection Welding Low Carbon Steel with Embossed Projections*, giving detailed information on projection welding techniques, projection forming tools, welding electrodes and joint design is available from the Taylor Winfield Corp., 1048 Mahoning Ave., Warren, Ohio.

Projection designs and welding techniques are found to vary with the thickness of the steel. Specific recommendations cover welding of projections embossed in thicknesses from 0.011 to 0.245 in. Macrophotos trace the development of a projection weld under different conditions.

Drawings are also included to show design of tools for forming the recommended projection shapes for best production results. Special electrode and tool designs are described to best accept commercial variables normally present in mass production.

For your free copy, circle No. 52 on Reader Information Card.

Temperature Chart

A new temperature conversion chart offered by Rosemount Engineering Co., 4900 W. 78th St., Minneapolis, Minn., permits rapid, accurate conversion from any scale —Kelvin, Rankin, Centigrade or Fahrenheit—to any other scale.

Range is from absolute zero to 16,000° C. Accuracy of rulings is approximately 0.01° below 100° C, 0.02° up to 300° C, 0.05° up to 800° C, 0.2° up to 2000° C, 1° up to 6000° C, and 5° up to 16,000° C. The chart is printed on both sides of single durable sheet, $8^1/_2$ by 11 in., punched for 3-ring binder.

For your free copy, circle No. 53 on Reader Information Card.

New Welding Machines

New NCG gasoline-engine-driven ac–dc welder/power plants, and diesel-engine-driven d-c welder/power plants are described in two bulletins available from National Cylinder Gas Div., of Chemetron Corp., 840 N. Michigan Ave., Chicago 2, Ill.

Diesel-engine model SDD-250 DC welder and model SDD-250-L DC welder with auxiliary a-c power plant are described in Bulletin NH-182. The welders have a rated output of 250 amp at 40 v. Features, specifications and dimensions are given, and optional equipment is described and illustrated.

Gasoline-engine model SGAD-225-L ac–dc welder/power plants are described in Bulletin NH-183. The unit produces 300 amp at 30 v a-c or 225 amp at 30 v d-c welding current. The welders and optional equipment are illustrated, and specifications and dimensions are given.

For your free copy, circle No. 54 on Reader Information Card.

Flame-cutting Machines

A complete line of Oxweld flame-cutting machines is described in a 28-page catalog (Form 1396) available from Linde Co., Div. of Union Carbide Corp. Machines described range in size from small, handy portable machines that can be carried around a shop by one man to huge multitorch shape-cutting machines capable of reproducing tens or thousands of the most intricate shapes and patterns in steel.

A new photocell tracer is also described. This new unit makes it possible to reproduce complicated metal parts from exact size pencil or ink drawings. The new tracer which can be used with stationary machines described in this catalog eliminates the need for expensive metal, wood or plastic templates or complicated silhouettes.

Also included are complete specifications for each machine, illustrations of typical installations, and a description of a wide variety of machine accessories.

For your free copy, circle No. 55 on Reader Information Card.

Pipe Thawing

Data on the fast, safe thawing of frozen water pipes with low voltage electricity is contained in a new bulletin (EW-243) from Hobart Brothers Co., Troy, Ohio. Subjects covered are: Who needs pipe thawing equipment, Electric method, Types of equipment, Instructions for successful thawing and Safety suggestions. Typical pipe thawing connections for use on home, farm and industrial piping are illustrated. Tables show amperes and time required for thawing steel pipe, recommended cable sizes and maximum amperage loads of Hobart arc welders recommended for pipe thawing.

For your free copy, circle No. 56 on Reader Information Card.

Low-cost Safety Course

An effective, low-cost safety training course for industrial foremen has been developed by the National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Written by training-expert Glenn Griffin of the University of Michigan's Bureau of Industrial Relations, the course consists of a series of six text booklets entitled 'Men and Motives in Safety Supervision," and a manual for discussion-group leaders.

RANSOME serves your positioning needs best because RANSOME is the only Complete positioning source

ONLY RANSOME PRODUCES A COMPLETE LINE OF POSITIONERS, MANIPULATORS, TURNING ROLLS, HEAD AND TAILSTOCKS, AND AUXILIARY EQUIPMENT... Ransome's manufacturing facilities are unmatched in the industry: our new factory in Houston, Texas is the world's largest plant devoted exclusively to the production of welding positioning equipment.

ONLY RANSOME MAINTAINS A COMPLETE LINE OF STANDARD MODELS . . . all sizes, all capacities . . . "off-the-shelf." This means that most of your positioning needs can be satisfied immediately, from stock! Of course, if your need is special, Ransome is delighted to custom design and build just for you . . . and nobody specializes as thoroughly as Ransome! Whatever you need in positioning equipment, Ransome has it in stock . . . or can make it to your exact specifications in the shortest possible time.

ONLY RANSOME HAS THREE STRATEGICALLY PLACED SHIPPING POINTS (our factory in Houston, and our warehouses in Los Angeles and Scotch Plains, N. J.) . . . wherever possible the equipment you buy is shipped FOB the **nearest** warehouse . . . saving you time, saving you shipping charges.

ONLY RANSOME HAS OVER 75 AUTHORIZED DISTRIBUTORS SERVING ALL 50 STATES . . . eager, and eminently able to put their special experience to work for you. (For the name of **your** Ransome distributor, fill in the coupon below.)

ONLY RANSOME OFFERS YOU THE CHOICE OF RENTING OR BUYING:

RENT: When you need the time and labor saving advantages of positioning equipment for a specific job, and do not want to appropriate large sums for heavy capital equipment . . .

BUY: When you have a continuing need and want to improve the overall efficiency of your welding procedures.

Ransome has been manufacturing positioning equipment since 1932 . . . Ransome **was** the pioneer, **is** consistently the leader in the field . . . Ransome equipment is world-renowned for rugged construction and precision engineering . . . for long life and perfect performance.

Ransome Company
MACHINE TOOLS FOR WELDING
Division of Big Three Welding Equipment Co.
RANSOME THE PIONEER IN POSITIONING FOR WELDING
Ransome Company, Scotch Plains, N. J.
☐ Put me in touch with your nearest dealer.
☐ Send more info on your new rental plan.
☐ Send Ransome Catalog & Guide to Positioning Equipment.
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Company
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Zone
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City

VISIT OUR BOOTH 305 AT THE WELDING SHOW. APRIL 18, 19, 20 — N. Y. COLISEUM

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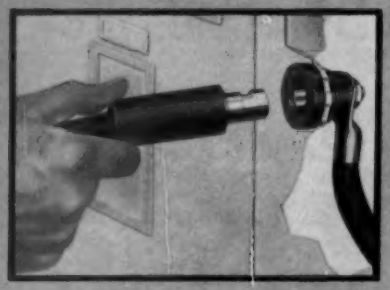

cam-lok
POWER CONNECTIONS

"The Standard of the Welding Industry"

CAM-LOK is standard equipment on various welding machines manufactured by . . .

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OMARK-GRAHAM
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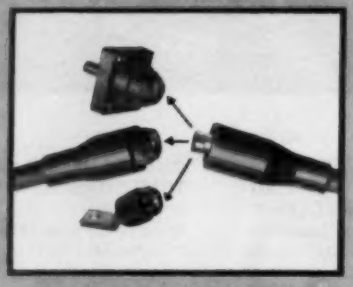
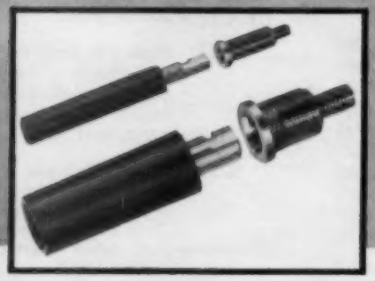




Modern power distribution in the welding industry demands a fast, high pressure positive connection with minimum resistance that is rugged, simple and economical. And leading welding machine manufacturers build Cam-Lok connections into their equipment for safe, full power distribution.

Make a better connection now with Cam-Lok, and speed up your production. Write for complete line catalog on plugs, connectors, and receptacles or detail your special requirements.

cam-lok DIVISION
EMPIRE PRODUCTS, INC., 9213J BLUE ASH RD., CINCINNATI 42, OHIO
For details, circle No 24 on Reader Information Card

The course offers practical instruction on ways a foreman can better understand his men and work with them toward safer, more efficient work practices.

For further details, circle No. 57 on Reader Information Card.

X-ray Wall Chart

A convenient reference wall chart for industrial radiographic departments, "The ABC's of Industrial X-ray Film Processing," is now available without charge from Eastman Kodak Co., Rochester 4, N. Y.

The wall chart (M4-26) provides a concise but comprehensive guide to recommend X-ray film tank processing procedures. It is intended to serve as a quick reference for radiography department personnel.

For your free copy, circle No. 58 on Reader Information Card.

Iron Powder Data

A technical data bulletin on iron powder has been compiled by the Alan Wood Steel Co., Conshohocken, Pa. Based on tests made in accordance with standards of the Metal Powder Industries Federation, the publication entitled *A. W. Iron Powder Technical Data Bulletin No. 2,* reports the results of extensive tests on grades of Alan Wood Iron Powder in performance graphs and tabular listings.

For your free copy, circle No. 59 on Reader Information Card.

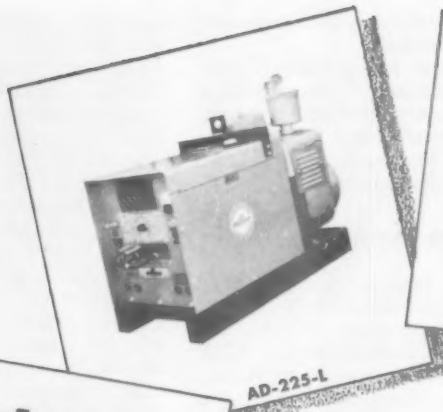
Semiautomatic "Squirtmobile"

A new bulletin is available from the Lincoln Electric Co., Cleveland 17, Ohio, on the operating features, construction details and application information on a new trackless carriage for Lincoln's semiautomatic Squirt welder. Designed to make long welds, this new magnetically supported travel unit is said to introduce a new degree of portability and flexibility previously unknown to submerged arc welding.

For your free copy, circle No. 60 on Reader Information Card.

Aluminum Bronze Alloys

Standard "off-the-shelf" items are described in a revised Bulletin (G-51a) by Ampco Metal, Inc., 1754 S. 38th St., Milwaukee 1, Wis. The 4-page, 2-color bulletin includes physical properties, recommended applications and current stock sizes of extruded solid rounds, centrifugally cast bars, extruded rectangles,



AD-225-L

D-250-WE

D-250-L

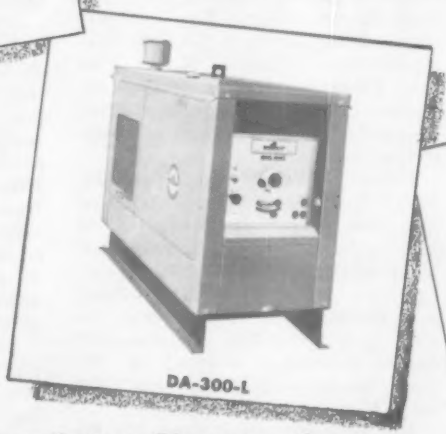
AEA-200-LE

FIRST and FINEST FAMILY of WELDER/POWER PLANTS

Miller was one of the first with a successful combination welder/power plant. This established a lead never lost notwithstanding the most widespread efforts at copying and duplication. Shown here are gas and diesel engine driven welders in d-c and a-c/d-c models.

In this group there is a welder/power plant size, type and price to meet every practical need—all available with field-tested accessories and trailers.

DD-250



DA-300-L

DAH-350-L

Complete specifications will be sent promptly upon request. Please indicate model or models.

miller ELECTRIC MANUFACTURING COMPANY, INC. • APPLETON, WISCONSIN

EXPORT OFFICE: 250 West 57th St., New York 19, N. Y. • Distributed in Canada by Canadian Liquid Air Co., Ltd., Montreal

For details, circle No. 9 on Reader Information Card

For Underwater Cutting of Non-Ferrous Metals PACIFIC UC PROVEN TOPS

- Requires Less Skill
- Costs Less To Operate

Continuous cutting in any position with full penetration is easily accomplished by any average operator. Greater quality performance compared to hollow carbon or tubular ceramic electrodes. Operates less expensively and quickly. Retains stability in normal water temperatures for 24 hours.

OTHER PACIFIC ELECTRODES

Choose from a complete line of stainless steel, phos bronze, nickel and other special alloy electrodes designed for either AC or DC. Heavy coating by method of extrusion guarantees a coating of uniform thickness, concentricity and density. Many unique and new features make your welding problems easier with Pacific.

For complete information write:

PACIFIC *Welding Alloys*

For details, circle No. 26 on Reader Information Card

STURDY, FLAMEPROOF WELDING CURTAINS

Any size—any shape. With hem to slip over pipe or angle iron frame or with grommets for lacing curtain to frame. Build your own frame. ABC curtains of durable, wear resistant fabric, are processed to render them flameproof. Send for sample of material—give size of curtains desired if price quotation is wanted. Over 25 years experience in flameproofing of fabrics.

ABC FLEXIBLE VENTILATION TUBING

Made from flameproofed fabrics. Plain fabric and wire reinforced fabric types. Easy to hang and couple. 4" to 24" diam. For ventilating large scale welding operations. Send for literature and prices.

AMERICAN BRATTICE CLOTH CORP.

331 King's Highway, Warsaw, Indiana

For details, circle No. 25 on Reader Information Card

rolled sheet and plate, die blanks and guide pin bushings.

These items are produced from special aluminum bronze alloys which have unusually high resistance to wear, corrosion and fatigue.

For your free copy, circle No. 61 on Reader Information Card.

Electron Beam Welding Unit

The Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., has just made available reprints of an article (Form ADR 128) by W. J. Greene, R. R. Banks and R. M. Niedzielski, titled "A New Electron Beam Welding Unit." The article was delivered as a paper before the AMERICAN WELDING SOCIETY convention in Los Angeles, April 1960, and appeared in the August issue of the WELDING JOURNAL.

Complete with graphs and illustrations, the article provides complete background information on the process. Following a general discussion of the apparatus, the three basic elements of the electron beam welder—electron-optics system, power supplies and vacuum system—are presented in detail. A final section reviews the electron beam welder's welding characteristics.

For your free copy, circle No. 62 on Reader Information Card.

Controlled Angle Torch

The availability of a technical and well-illustrated bulletin, WC-60, describing the recently developed Controlled Angle Torch for tungsten inert gas arc welding has been announced by Falstrom Co., 222 Falstrom Court, Passaic, N. J. The new torch features a completely flexible head that permits control of angular position as well as longitudinal movement.

Bulletin WC-60 describes the design features and applications of the new torch. It illustrates its use in hard-to-reach corners and at unusual angles. Complete specifications, including length, weight and materials of construction are also included. The water-cooled model illustrated is rated at 180 amp, ac–dc continuous duty (300 amp, ac–dc intermittent duty).

For your free copy, circle No. 63 on Reader Information Card.

Manganese Steel Surfacing

An illustrated two-page engineering data sheet in color (No. 56), entitled "Surfacing Austenitic Manganese Steel with Walmang No. 3 and Walmang No. 8," is now available from Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich. The data sheet discusses the use of manganese steel in industry and the need for special care in repairing worn or broken parts made of the material. Techniques for best results are suggested.

Complete recommendations for application of the two alloys, one a manganese-nickel electrode (Walmang No. 3) and the other a manganese-molybdenum semiautomatic wire (Walmang No. 8), are also included.

For your free copy, circle No. 64 on Reader Information Card.

Welding School

A new bulletin outlines the program in arc welding education available at The Lincoln Electric Co., Cleveland, Ohio. The Lincoln Welding School, in operation since 1917, teaches the skills necessary to use various metallic arc welding processes. A basic five week course covering fundamentals of manual metallic arc welding can be expanded to over eleven weeks of training by including such subject matter as pipe welding, hardsurfacing, alloy welding, semiautomatic submerged arc welding and tungsten inert gas welding. The bulletin also contains a registration blank and summary of the fees charged.

For your free copy, circle No. 65 on Reader Information Card.

Mixer Type Welding Torches

Gas welding torches—the Oxweld W-45 and W-47—capable of welding any metal thickness from 28 gage sheet to heavy plate are described in a new eight-page booklet available from Linde Co., Div. of Union Carbide Corp., 270 Park Ave., New York 17, N. Y. Unique feature of the torches is their ability to handle gas flows as low as 2 cfh for precision welding, or total flows as high as 1500 cfh for heavy heating operations.

All that is needed to convert the torch from light to heavy-duty work is a fast and simple change of welding heads. Each size welding head used with the torches has an individual patented cartridge-type mixer that provides thorough mixing of gases and eliminates flashback. "O" ring seals eliminate metal-to-metal seats and prevent gas leakage.

Handy cutting attachments that quickly convert the torches from welding and heating to flame-cutting

Model 500-40 VS
(500 amp rated output)

For jobs where only the best will do—

NEW GLENN V/S VARIABLE SLOPE CONSTANT VOLTAGE POWER SUPPLIES

for all consummable-electrode automatic and semi-automatic welding processes, including:

MIG - SHORT ARC
SUBMERGED ARC - MAGNETIC FLUX

New GLENN V/S power supplies are totally new from basic transformer design to their exclusive new linear slope control. They can be precisely "tuned" to the exact arc characteristics needed to produce any type of metal transfer and deposition desired. The result is improved weld quality, appearance, speed and economy.

Model 300-40 VS
(300 amp rated output)

Basic features

1. **NEW TRANSFORMER DESIGN** increases efficiency, improves voltage regulation and minimizes effects of line voltage fluctuations.

2. **STEPLESS VERNIER SLOPE CONTROL** provides continuous linear slope control from flat no-slope to maximum slope; in two overlapping ranges.

3. **EXTENDED OUTPUT VERNIER VOLTAGE RANGE** provides effective dc welding (loaded) voltages from approximately 8 to 42 volts, depending on slope settings.

WHEN SPECIFICATIONS ARE CRITICAL and weld quality, uniformity and appearance must be kept high, you'll be hours and dollars ahead to specify GLENN V/S power supplies. Why not get the facts? Write us today for literature, specifications; please address Dept. 138.

GLENN PACIFIC
POWER SUPPLY CORPORATION

703-37th Avenue • Oakland 1, California
Originators of CV Power Supplies

Eastern Office
615 Riverwood Ave., Point Pleasant, N. J.

Midwestern Office
640 So. York, Elmhurst, Ill.

✻ GLENN Balanced Wave Power Supply for TIG Welding ✻ GLENN Manual and Stud Welder Power Supply ✻ GLENN Arc Gouger Power Supply ✻ GLENN Constant Potential Welder for "Gang" Manual Welding ✻ GLENN Industrial Power Supplies and Heavy Duty Variable Voltage Transformers

3

For details, circle No. 27 on Reader Information Card

NEW! WYPO FILE FREE!

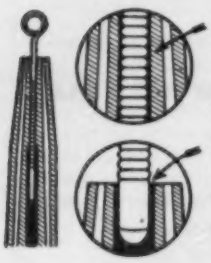
NEW POLISHED ALUMINUM CASE DESIGNED TO SERVE AS HANDLE FOR THE NEW FILE

Let Your Local Welding Supply Dealer Explain Why "YOU GET SO MUCH MORE" With . . .

WYPO
Wipes and Polishes
the World's Finest
CUTTING & WELDING TIP CLEANERS

FREE! NEW, SPECIALLY DESIGNED WYPO POLISHING FILE INCLUDED IN EACH SET

More Exclusive WYPO Features



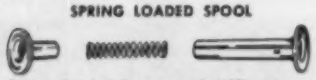
These rounded outer edges of cleaning ridges clean and polish tip orifice without scratching or cutting.

This smooth pilot guides WYPO Tip Cleaner into tip. Will not enlarge or damage tip port.

This cross section view of WYPO Cleaning Surfaces shows these exclusive features: Rounded cleaning surfaces that won't jam or cut.

Straight sided valleys insure thorough cleaning by removing all waste.

SPRING LOADED SPOOL



Spring loaded brass spool. Will not rust. Holds cleaners securely in case.

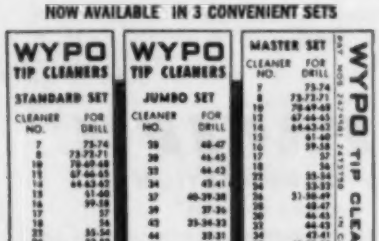
DOUBLE WOUND EYES

Insures longer life for small sizes of WYPO Tip Cleaners. Will not pull out of case.

STAINLESS STEEL POLISHING FILE

Specially designed WYPO File furnished free in each set

NOW AVAILABLE IN 3 CONVENIENT SETS



STANDARD SET OF (12) Cleans (27) Drill Sizes No. 75 to 49 Incl.

JUMBO SET OF (9) Cleans (19) Drill Sizes Nos. 60 to 38 Incl.

MASTER SET OF (31) Cleans (46) Drill Sizes Nos. 75 to 30 Incl.

Replacement cleaners and files available. Cleaning Range—Cleaner No. & Drill Nos. stamped on back of each case. WYPO GIVES YOU MORE!

SOLD BY LEADING WELDING SUPPLY DEALERS

MAITLEN AND BENSON, INC.
1395 Obispo St., Long Beach 4, Calif.

For details, circle No. 20 on Reader Information Card

on all metal thicknesses up to 8 in. are also described. Complete ordering information and performance data on a complete selection of welding heads and cutting nozzles is included.

For your free copy, circle No. 66 on Reader Information Card.

Resistance Welding Machines

A new 12-page brochure, in color, FEDERAL BT-60, issued by the Federal Machine and Welder Co., Warren, Ohio, illustrates and describes their line of resistance welding, machines in all phases, spot, projection, seam, roll seam, portable welders, aircraft spot and seam, flash, multispot and automated machines.

For your free copy, circle No. 67 on Reader Information Card.

Multiarc Welding Controls

Multioperator resistor units for individual control of welding arcs in multiarc systems are described in a four-page bulletin from J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y. The "Weldline" units come in compact, lightweight 2-, 4- and 6-operator models.

In addition to d-c metallic arc welding with coated electrodes in all positions, the publication points out that the units may be used to control other types of electric arc welding, including the gas-shielded tungsten arc and consumable electrode processes. Switches on the front of each drawer in a unit make it easy for individual operators to vary the current in steps as small as one ampere for accurate welding control.

For your free copy, circle No. 68 on Reader Information Card.

Design of Steel Structures. By Boris Bresler and T. Y. Lir. Hard Cover, 6 x 9 in., 710 pp., indexed. Published by John Wiley & Sons Inc., New York. Price $9.75.

The book is intended as a textbook for chemical engineers studying design of steel structures. It can be used for both elementary and advanced students, depending upon the chapters that are studied. It is also a good reference work for engineers in the field.

It has an extensive treatment of welded connections and design. It begins with the fundamentals of welding and proceeds to explain and develop various formulas that appear in current specs and codes. The book has a good treatment of the AMERICAN WELDING SOCIETY bridge specifications and AWS building code, and also points out why these documents contain certain requirements.

This book, combined with the *California Manual of Bridge Design Practice*, presents a foundation for the designer of steel structures. It gives him the background information as well as practical guides for step-by-step procedure.

California Manual of Bridge Design Practice. Hard Cover, 8 1/2 x 11 in., 638 pp. State of California, Department of Public Works, Division of Highways, Bridge Department. Price $12.50.

This book is divided into sections on bridge economy, review of moment distribution, bridge loadings, slab bridges (longitudinally reinforced), design of T-beam high way bridges, design of box-girder highway bridge, simple-span rolled-beam bridges, design of a welded-girder highway bridge, simple-span composite girder bridge, design of a deck-girder railroad bridge, design of through-girder railroad bridge, simple-span truss bridge, theory of prestressed concrete and design of a prestressed concrete girder.

Each section describes the application of theory, interprets the AASHO or AREA design specifications and provides a complete step-by-step example of the design. Appropriate charts, tables and graphs are included. Eight of the sections also describe the design of various types of substructures.

Of particular interest is Chapter 8—Design of a Welded-girder Highway Bridge. It contains an excellent discussion of welding in general, as it applies to bridges. It also lists the advantages and disadvantages of welded bridge designs. This is a question that is constantly being raised by those not familiar with welding. By using this book, any structural designer should be able to design a satisfactory welded bridge.

New Products

Torch Produces Heat Without Fuel

The "Plasma Torch," a device that uses a new principle to generate heats approaching the temperature of the sun, yet consumes no fuel whatsoever, has been announced by Amperex Electronic Corp., Div. of North American Phillips Co., Inc., Hicksville, L. I., N. Y.

The torch operates by using the energy of a high-frequency electromagnetic field to break up and ionize gas molecules into their component atoms and then allowing them to recombine into their original state.

When recombination occurs, the absorbed energy is said to be liberated in the form of heat. Experiments with the torch have been conducted with ordinary nitrogen. Since it is never consumed, the nitrogen—or any other suitable gas—can be used again and again.

Temperatures in excess of 3000° C have reportedly already been achieved, and experiments are now under way to reach 5700° C, the temperature of the sun's surface. Another unique torch characteristic is that none of its parts ever heat. It is said that if the system is suddenly turned off and the area near the flame is touched, it is found to be cold. According to Amperex the torch, therefore, can last indefinitely. The only component that will eventually have to be replaced is said to be the electron tube or magnetron used to generate the electromagnetic field. In one unit, the Amperex Type 5866 tube is a $20 standard transmitting tube; a second unit used is the Amperex Type 7292 magnetron.

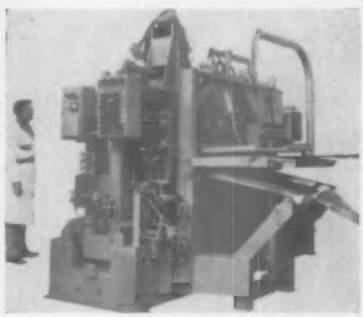
Important and diverse applications in a variety of industries are said to be foreseen: investigation of missile reentry, spraying high melting point metals and ceramics, petroleum cracking, welding, etching, machining, chemical purification and processing.

For details, circle No. 101 on Reader Information Card.

Seam Welding of Strip Coils

The Taylor Winfield Corp., 1048 Mahoning Ave., Warren, Ohio, has announced a resistance seam welding machine for joining strip coils. This unit is reported as having many new features to speed the welding of thin gage steel strip in building up large diameter coils.

In addition to a built-in strip shear, automatic conditioners for the weld wheels and strip piercing punches (for identifying the weld in later operations); this machine is said to be equipped with an automatic preloader for the head end of next coil. This feature reportedly allows the operator to load and pre-



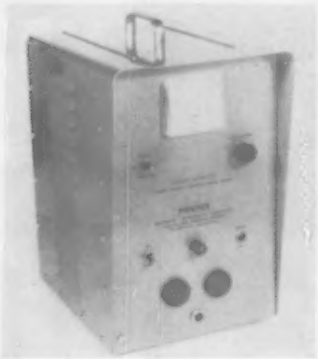
pare a coil for welding as the previously joined coil is passing through the machine. Then, when the coil end is reached, an automatic cycle mechanically feeds this prepared head end into welding position, square shears the strip ends and quickly welds them together.

Total time for strip handling, shearing and welding is said to be 15 sec for a 46-in. strip; the machine can handle strip ranging in thickness from 0.004 to 0.036 in.

For details, circle No. 102 on Reader Information Card.

Miniature Power Supply

A 40 w-sec stored-energy welding power supply designed especially for miniature electronic welding is announced by the vacuum tube products division of Hughes Aircraft Co., 2020 Short St., Oceanside, Calif.



The power supply, designated the VTW-29, is said to deliver a step-free adjustable range of power of 0.01 to 40 w-sec in 0.001 sec. A pulse width of 1 msec assures no burning or discoloration of material. Weld speeds are up to 120 spots a minute, according to the manufacturer. The unit occupies less than 1 sq ft of bench space.

For details, circle No. 103 on Reader Information Card.

CO_2 Welding Torches

A new "Automanual" welding gun for all metal-arc inert-gas-shielded and carbon dioxide-shielded welding processes, and an automatic torch for metal-arc and tungsten-arc welding, are announced by National Cylinder Gas Div., Chemetron Corp., 840 N. Michigan Ave, Chicago 11, Ill.

The AM-7 gun and the A-10 torch have interchangeable barrels—the gun is fitted with an adjustable pistol grip, and the torch can be mounted singly or in a standard mount holding two torches for parallel or tandem welding.

The units reportedly provide complete shielding, using 25% less gas than any previous gun or torch,

AM-7 Welding Gun

RIGHT ON THE BUTTON EVERY TIME!

The swiftest, simplest, surest way to fasten metal . . .

NEW BUTTON WELD

BY

A.O. SMITH

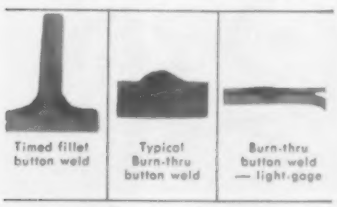
For details, circle No. 29 on Reader Information Card

C-OMANUAL button welding boosts output . . . cuts rejects

Here's one button the zipper hasn't replaced. In fact, this button process is the latest development in welding — a development that has replaced old-fashioned spot-resistance welding and riveting.

Armed with a lightweight hand gun using A. O. Smith's CO_2 C-OMANUAL process, the operator works from one side only. The button burns through to fasten steel up to 3/16 in the downhand position and 3/64 in the vertical. And welders take their helmets off to button welding — no need to wear one with this A. O. Smith process. Simple, too! Special operator training is not required. Just place the gun . . . pull the trigger! Hold until the welding stops *automatically*. Perfect button weld every time . . . no flux to clean.

Choice of nozzles permits welding of any of the standard joints (lap, fillet, butt).



Timed fillet button weld | Typical Burn-thru button weld | Burn-thru button weld — light-gage

Other button blessings include quality low-hydrogen weld metal, high deposition rates, full utilization of weld metal for low overall costs. Put this high-speed production tool to work for you. Send for Bulletin MW-253 for details.

Through research . . . a better way

A.O.Smith
CORPORATION
WELDING PRODUCTS DIVISION
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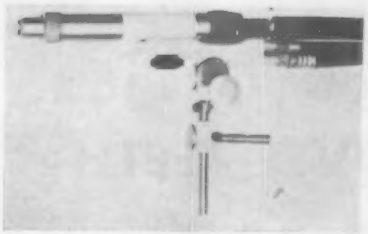
A.O.Smith INTERNATIONAL S.A. Milwaukee 1, Wis. U.S.A.



A-10 Automatic Torch

according to NCG. The multiuse barrel is said to run cool, even at maximum 600 amp. Hose kinking is minimized because all cable, hose and wire conduit enter at one location (the rear of the gun) in line with the flow of welding wire.

Both units can be used to weld ferrous and nonferrous metals. Consumable-electrode length between the current contact and the arc is adjustable by means of a knob at the rear of the gun and the torch. The tungsten position can be adjusted during automatic TIG welding with the torch.

For details, circle No. 104 on Reader Information Card.

Heavy-duty Industrial X-ray

A new heavy-duty industrial X-ray machine that produces images of "unmatched sharpness" for testing and inspection has been announced by Picker X-Ray Corp., 25 S. Broadway, White Plains, N. Y., the largest producer of X- and gamma-radiation equipment.

Sharper X-ray pictures are made possible by the tube's 0.012-in. (0.3-mm) focal spot, the smallest of any X-ray unit, the company explained. The unit is said to have a rotating anode tube with a continuous rating of 6 milliamp at 150 kv, twice the output of a stationary anode tube.

"This 150-kv X-ray machine can reveal very small defects and is especially suited for aircraft and other industries requiring large amounts of nondestructive inspection," said John A. Reynolds, Picker technical director. "Its controlled high-radiation output allows shorter exposures and the water-cooled tube permits handling of heavy traffic without overheating."

A counter weighted 3-in. square mast reportedly eliminates vibration and assures clear images. The mast can be pivoted 360 deg. and fits under an 8-ft high ceiling. The unit also has a telescoping tube arm that provides 16-in. cross-travel and an axis for complete rotation of the tube hanger.

For details, circle No. 105 on Reader Information Card.

Gas Tungsten-arc Cutting

Metalworking shops have at their disposal a fabricating tool that may be used for both welding and cutting. Complete fabrication, from cutting of metal to final welding into a finished product, can now be accomplished with a single Heliarc torch. Either manual operation or mechanized fixturing may be used, according to Linde Co., Division of Union Carbide Corp., 270 Park Ave., New York 17, N. Y.

Cutting is accomplished by increasing current density above good welding conditions, while utilizing Linde argon-hydrogen shielding mixtures. Normal gas flow rates (40–60 cfh) are sufficient to transfer energy across the arc and displace the molten metal. Good kerf quality is obtained on one side of the cut, while the other side is trimmed away as scrap. Simple scratch-starting is employed and arc length is not critical. Any standard d-c power equipment with a 70-v open circuit may be used for Heliarc cutting of metals within a range of $\frac{1}{8}$ to $\frac{1}{2}$ in. thick. Typical Heliarc cutting speeds are 40–60 ipm on $\frac{1}{8}$ in. aluminum and 20–40 ipm on $\frac{1}{8}$-in. stainless steel, using Linde H-35 shielding gas.

For details, circle No. 106 on Reader Information Card.

Solder-type Alloy

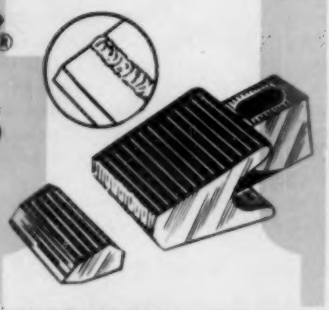
A new solder-type alloy designed especially for electrical and electronic work is available from the Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y. Neu-Tec-Tronic 157BN alloy is said to be 50% more electrically conductive than the standard 50-50 lead-tin solder. Its highly active flux core is inert after carbonization, with residues which are noncorrosive and nonconductive and do not support fungus growth. Low melting point and high solidification rate to prevent hot-shorting and minimize joint movement while plastic are other features of this new alloy.

THREE GOOD WAYS TO... REPOINT SHOVEL TEETH - FAST

COSTS LESS THAN NEW TEETH!
QUICK, EASY WELDING METHOD!

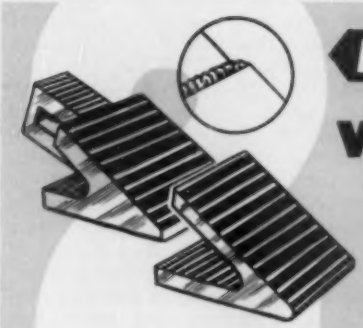
HEAVY-DUTY
MANGANAL®
11% - 13½% MANGANESE-NICKEL STEEL
WEDGE BARS

Available in many sizes to fit any repointing requirement.



HEAVY-DUTY
MANGANAL®
11%-14% MANGANESE STEEL
WING-DING®
INDIVIDUAL SLIPOVERS

Available in nine sizes. Builds up tooth face and repoints in one operation.



SS CRESCENTS
WEAR-RESISTANT ALLOY STEEL
TOOTH POINTS

Available in four sizes. For quick sharpness to give easy digging.

Available from all welding distributors.
Nearest Distributor Upon Request. Send for Helpful Literature.

MEMBER NATIONAL WELDING SUPPLY ASSOCIATION

STULZ-SICKLES CO.
929 Julia Street • Elizabeth, New Jersey

For details, circle No. 35 on Reader Information Card

The alloy can be applied with soldering iron, torch, by hot plate or induction heating. Deposits will accept a wide range of plating including gold, silver, nickel, platinum and cadmium. Available in 0.030 and $^1/_{16}$ in. sizes.

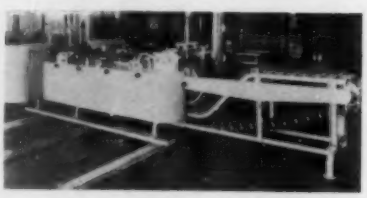
For details, circle No. 107 on Reader Information Card.

Welding-rod Packing Machine

A machine that reportedly not only automatically packs and seals welding rods in a corrugated carton but also individually prints and glues the identifying label across the top of the sealed container is available for export to the United States from Machinefabriek P. van Houten, Wormer, Holland, according to the Netherlands Trade Commission, 551 Fifth Ave., New York 17, N. Y.

The operation follows a simple process of stacking the cartons to be filled in a magazine from which the bottom carton is withdrawn as needed. The folded carton is opened by means of metal blades which pass the open welding rod containers to a chain conveyor. Packing operations are performed by the use of compressed air, powered by available electric current. The unit can pack 12 containers per minute.

Filling of the cartons is accomplished by first taking the previously counted rods and placing them in a rectangular sloping tray. This

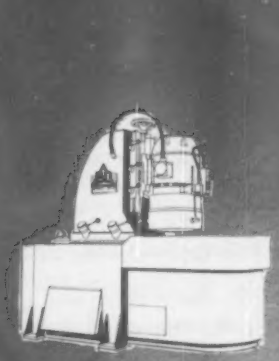


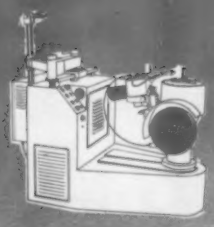
feeds into a chute, and the rods are fed to the container as it pauses under the mouth of the chute by means of a plunger.

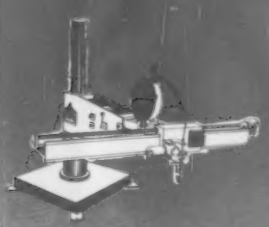
The chute and plunger's movements are controlled electromagnetically. As a safety precaution, the machine has an automatic shutoff in case a rod becomes stuck, or if a carton is inaccurately positioned.

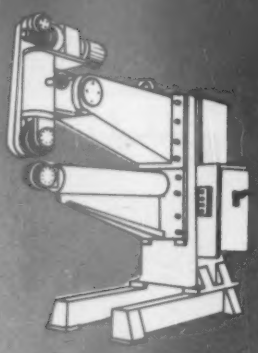
The machine is driven by a 1.1 hp, 220/380 v, 3-phase electric motor with a wormgear, and can be adjusted to pack 14- or 18-in. long containers. Dimensions of the packing machine are approximately $17^1/_2$ x $11^1/_2$ x 5 ft.

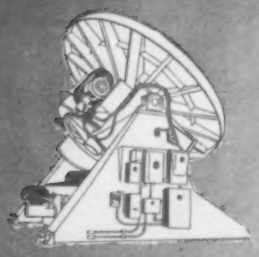
For details, circle No. 108 on Reader Information Card.











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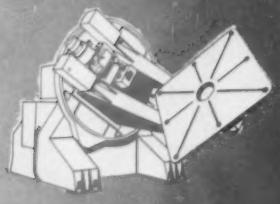
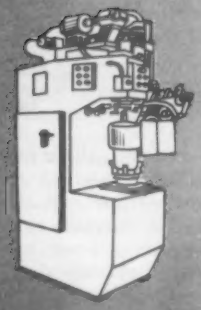
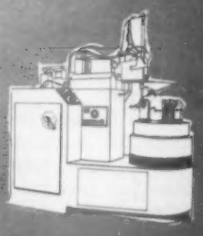






The Mark of Quality in Automatic Arc Welding Machinery

BERKELEY DAVIS INC.

DANVILLE, ILLINOIS

Subsidiary of The McKay Machine Co., Youngstown, Ohio.

For details, circle No. 31 on Reader Information Card

Transformer for Frozen Pipe

The Hobart Brothers Co., Troy, Ohio, has announced the availability of a small Porta-Thaw transformer that makes it possible to thaw frozen pipes by using the ordinary domestic a-c electric circuits—110 or 220 v, single-phase, 50 or 60 cycles, and it can be carried by one man.

It is complete with a 10-ft power cable with plug and receptacle and two 20-ft thawing cables with lugs and pipe clamps. The case measures only $16^{3}/_{8}$ x $11^{1}/_{2}$ x $10^{5}/_{8}$ in. and the unit weighs 63 lb. Convenient carrying handles are provided.

The transformer is rated at 300 amp, 10 v on 100% duty cycle. Four output terminals of long-life bus-type provide for three thawing steps—high, medium and low. There are no electrical connections between the power line and the output terminals making it as safe to operate as a household appliance.

For details, circle No. 112 on Reader Information Card.

Welding and Cutting Outfit

A complete medium-sized full capacity welding and cutting outfit, the Marquette Star-Jet, now available in a rugged tool box as the Marquette Redi-Pac, has been announced by Marquette Manufacturing Co., 307 E. Hennepin Ave., Minneapolis 14, Minn., as the newest addition to the gas welding equipment line of this company.

The outfit includes full-size heavy-duty gas regulators, full 25-ft double line hose, four of the "most useful" welding tips, one medium-size cutting tip and accessories. A full

range of welding, heating and special purpose tips is said to be available to fit the Star-Jet Torch Handle. In addition, a broad range of cutting tips is also available to fit the rugged cutting assembly.

Reportedly nearing the ultimate in efficiency, the outfit saves time and labor in many ways. It is designed to handle most welding lines; tool, die and maintenance departments. Flexible, the outfit is said to weld all metals, brazes, solders and provides heat for the bending and forming of steel, loosens frozen bolts and quickly cuts steel.

For details, circle No. 113 on Reader Information Card.

AC-DC Metal-cutting Electrode

A new formulation for its Eutec-Chamfer-Trode metal cutting electrode, which permits its use with ac as well as dc was recently announced by the Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y., as part of its 20th Anniversary Parade of New Products. Applications include chamfering, beveling, grooving, in preparation for welding; making fast inexpensive rough cuts to be finished on machine tools for keyways and similar work; and removal of hard surfacing, frozen bushings, etc.

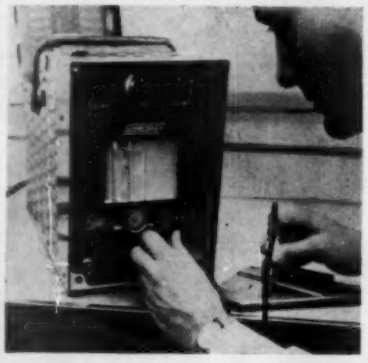
The new electrode retains its fast efficient performance when used with d-c equipment, and adds excellent arc stability to give the same performance with any industrial-rated a-c welding units, without cycling or arc cutout, and

with excellent restriking qualities for intermittent gouging. Operation is within the same amperage range for ac or dc. With its a-c capability, the electrode can be brought to the work rather than bringing the work to where dc is available.

For details, circle No. 114 on Reader Information Card.

Ultrasonic "Micrometer"

Equipped with a newly developed caliper attachment, a Sonoray ultrasonic flaw detector may now be used to measure thickness of metals and plastics, from one side, to accuracies within ±0.010 in. Both the caliper attachment and the basic instrument itself are marketed by Branson Instruments, Inc., 40 Brown House Rd., Stamford, Conn.



Operation of the caliper is simple. It consists essentially of a fixed, scribed, vertical line and a second line on a slider, movable across the face of the cathode-ray tube. A synchronized dial indicator measures the amount of this motion, permitting the operator to determine thickness directly, without calculations or interpolation.

The caliper attachment is available separately, for mounting on existing Sonoray detectors, or it may be ordered installed on the instrument. It weighs approximately one pound.

For details, circle No. 115 on Reader Information Card.

Projection Welding of Automobile Horns

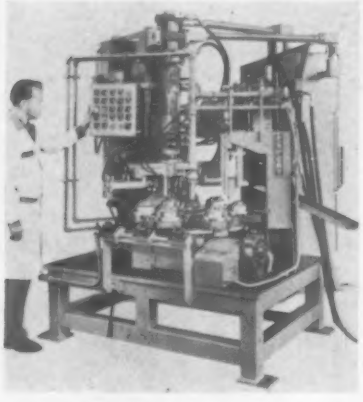
A new 6-station rotary index automated welding machine that projection welds an automatic horn motor field coil cup to a base plate at a production rate of 1000 assemblies per hour is now available from Expert Welding Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.

To achieve these high production rates, the machine incorporates un-

usual automatic features and a high-speed index drive.

An automatic air-operated hold-down fixture maintains the proper height between the flange of the base plate and the face of the cup during the welding operation.

The index table is driven by the Expert standard cam index drive. The index table contains six identical fixtures that locate and support the cup and base plate. The cup and base plate are manually loaded into the fixture in Station 1. The



fixture then indexes through idle Station 2 to Station 3.

In Station 3 the hold-down fixture automatically aligns and holds the assembly in correct position while four welding guns projection weld the cup to the base plate in four places. After the welding operation has been completed, the hold down fixture and welding guns automatically retract and the part is indexed through idle Station 4 to Station 5 where the part is automatically unloaded from the machine.

The 6-station rotary index welding machine occupies a floor space of about 5 by 4 ft and is 8 ft high; it is electrically sequenced and air operated.

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Resistance Welding Alloys

Rolled plates, available in a series of new large sizes from stock, are being offered by Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 1, Wis., to meet RWAA Classes II and III as well as other high-conductivity applications.

Produced in two resistance welding alloys—AMPCOLOY 95 and 97—the new sizes are considerably larger than have ever been offered before. Thicknesses include $^3/_8$, $^5/_8$, $^7/_8$ and $1^1/_8$ in. Depending upon the thickness, maximum widths range from 48 to 60 in. maximum lengths from 96 to 156 in.

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Safety Spectacles

Air Reduction Sales Co,. 150 E. 42nd St., New York 17, N. Y., has recently introduced a new line of general purpose safety spectacles.

Described as tough enough to withstand rough use, yet lightweight, cool and comfortable, Airco plano-type spectacles come in three models. Available are Airco 60, without sideshields; Airco 61, with partial sideshields; and Airco 62, with full sideshields.

Another feature of the spectacles is the simplification of fitting problems through the use of a specially designed "universal" bridge.

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PRODUCTS OF S.M.S. CORP., BIRMINGHAM, MICH.

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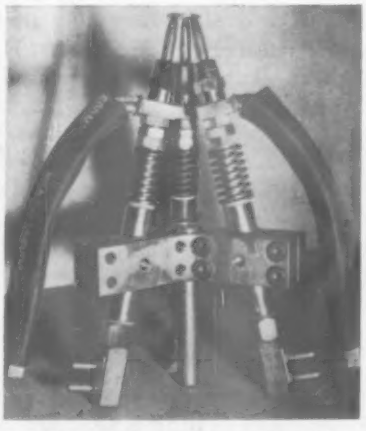

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HANDY & HARMAN BRAZE 541

Titeflex operator brazes assembly with torch and hand-fed Handy & Harman Alloy BRAZE 541. *Titeflex is unique in that it makes flexible hose assemblies from raw material to end product—"From End to End, Inside and Out, made RIGHT In Our Own Plant."*

This Springfield, Massachusetts, manufacturer of aircraft and missile fuel, lubrication and hydraulic lines finds that silver alloy brazing with Handy & Harman BRAZE 541 meets rigid operating requirements "all the way down the line."

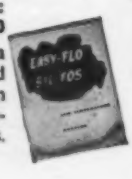
The tubing and fittings of many of the wide range of assemblies made by Titeflex are 321, 316 and 347 stainless steel and Monel. Brazing is a hand torch, wire and HANDY FLUX operation.

BRAZE 541 is a plastic alloy which melts at 1325° F and flows at 1575° F. Its strength—in shear—at elevated temperatures is 21,500 psi at 500° F and 15,000 psi at 750° F. This alloy's ductility in resisting stress and vibration is very high and its resistance to oxidation and corrosion is equally impressive. The composition of BRAZE 541 is 54% silver, 40% copper, 5% zinc and 1% nickel. It meets AMS Specification 4772.

Aircraft and missile component manufacturers and fabricators are finding—to their and their products' benefit—that Handy & Harman silver alloy brazing is the full and *final* solution to their metal-joining problems. BRAZE 541 is but one of a large family of Handy & Harman alloys, for both low and high temperature applications. We would like to more fully acquaint you with BRAZE 541 and with the advantages that come naturally to silver brazing as a metal-joining (both ferrous and nonferrous) method. Handy & Harman, 82 Fulton Street, New York 38, N. Y.

FOR A GOOD START: BULLETIN 20

This informative booklet gives a good picture of silver brazing and its benefits... includes details on alloys, heating methods, joint design and production techniques. Write for your copy.



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Welding equipment is designed, developed and refined, but eventually it must be redesigned. LINDE'S new SIGMATIC line of "Mig" welding equipment is a product of this evolution... plus LINDE'S vast experience with more inert-gas and consumable-electrode processes than any other company in the world. The SIGMATIC line is the most-versatile semi-automatic equipment available anywhere—one machine for:

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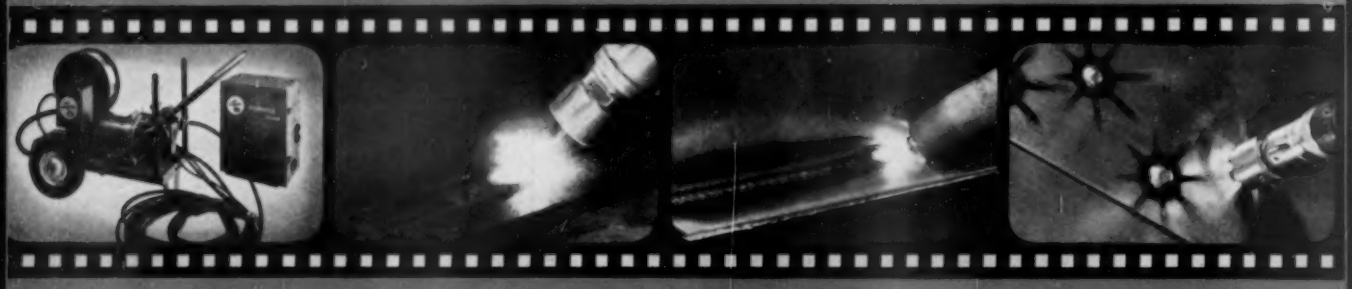
- **...in all welding positions—vertical, overhead or downhand**
- **...with all shielding gases—argon, helium, CO_2, or their mixtures**
- **...and all wires—hard or soft, solid or tube**
- **...on all weldable metals—carbon steel, stainless, aluminum, magnesium, titanium**
- **...on all thicknesses—sheet metal and up**

See next page for details.

SIGMATIC



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WRC

SUPPLEMENT TO THE WELDING JOURNAL, FEBRUARY 1961

Fundamentals of Weld Behavior Under Hindered Contraction

Factors affecting separating force must be recognized when considering welds which cool under conditions of hindered contraction

BY R. E. TRAVIS, J. M. BARRY, J. V. ROBINSON, W. G. MOFFATT, AND C. M. ADAMS, JR.

ABSTRACT. In hindered contraction of restrained test welds, the development of self-imposed loads has been found to depend systematically on the geometry and stiffness of restraint, the strength and hardenability of the filler and plate, and arc energy input. In the presence of a transverse bending moment, the factors which favor high restraint stresses also promote cracking, but without the bending moment cracking will not occur. Significant mechanical effects, such as increase of load or initiation of cracking, often take place long after the weld has cooled to room temperature.

Introduction

In the fusion welding of engineering structures, hindered solid contraction of cooling welds inevitably results in stresses and distortions. Their magnitudes depend on the geometric, material and thermal characteristics of the system. The over-all pattern depends on exceedingly complex interplay of plastic and elastic deflections, solid state transformations, and transient heat flow, the details of which are but vaguely understood. Much experimental and analytical work is needed to gain systematic comprehension of the physical and metallurgical behaviors involved, especially where weld cracking is concerned.

In such pursuits it is essential to gain experimental information during the formative period, immediately following welding, on the way in which temperature, stresses and strains change simultaneously. To this end a program directed to generation of experimental methods and applied to

Fig. 1—Horizontal lever arm apparatus with cracked specimen

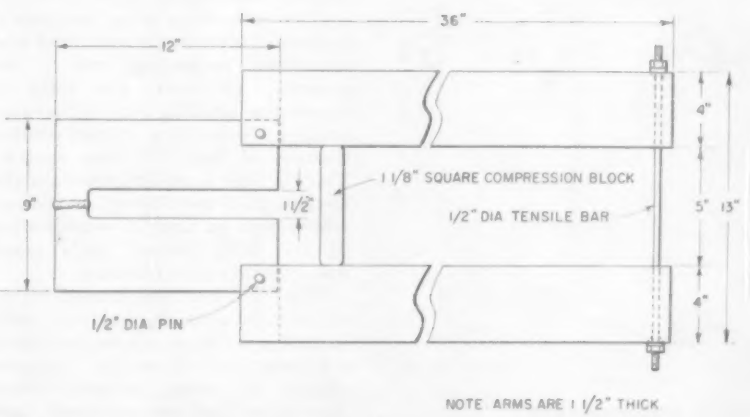

Fig. 2—Horizontal lever arm apparatus design

Except for J. V. ROBINSON, the authors are associated with the Massachusetts Institute of Technology, Cambridge, Mass., as indicated—R. E. TRAVIS, Staff Member, Div. of Sponsored Research; J. M. BARRY, Research Assistant, W. G. MOFFATT, Assistant Professor of Metallurgy; C. M. ADAMS, JR., Associate Professor of Metallurgy. J. V. ROBINSON is Engineer in Charge, New Zealand Government Ministry of Works Central Laboratory, Wellington, New Zealand.

Paper presented at AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26-29, 1960.

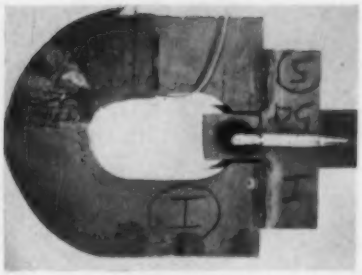

Fig. 3—"U"-bar with specimen

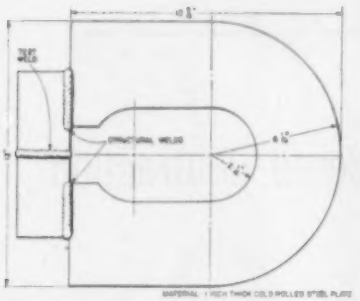

Fig. 4—"U"-bar design

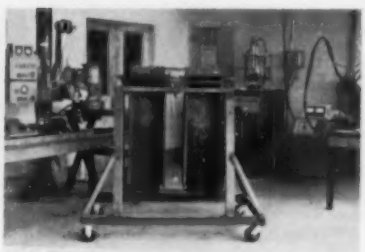

Fig. 5—Vertical lever arm apparatus with specimen

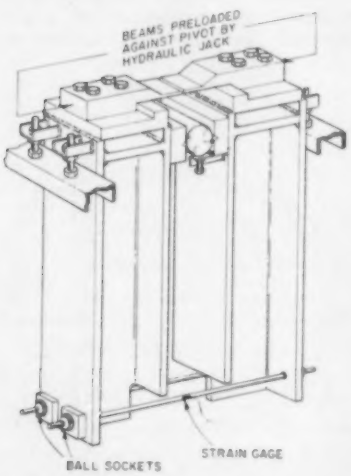

Fig. 6—Vertical lever arm apparatus design

Table 1—Compositions of Plate and Filler Alloys Used in Automatic Welding

	C	Mn	Si	S	P	Mo	Ni	Cr	V
Plate									
A	0.29	1.73	0.22	0.020	0.018	0.48	...	...	...
B	0.27	1.67	0.20	0.021	0.016	0.46	...	...	...
Filler									
A	0.35	1.00	0.45	0.020	0.020	...	...	1.10	0.18
B	0.05	1.31	0.50	0.017	0.007	0.45	1.28	0.10	0.13

the problem of weld cracking in armor steels, was initiated in 1955, and some results have already been reported.[1] This paper is offered in the nature of a progress report on further results and refined methods of study especially applicable to the welding of heat treatable steel.

Materials and Procedures

Three different sets of apparatus were used to study hindered contraction under different geometries and magnitudes of restraint: a horizontal lever arm shown in Figs. 1 and 2, a "U" bar shown in Figs. 3 and 4, and a vertical lever arm shown in Figs. 5 and 6. Of the three apparatus, the horizontal lever arm has the lowest and the vertical lever arm the highest overall stiffness; the spring constant of the "U" bar is intermediate between that of the horizontal and vertical lever arm apparatus. Through the use and location of pivot pins, it is possible with the horizontal lever arm to impose any desired ratio of transverse bending moment to separating force on the specimen weld, and it is also possible to restrain welds in the absence of a transverse bending moment. The horizontal lever arm has a movable fulcrum, which permits a wide degree of adjustability in the elastic stiffness of the restraining system. The "U" bar accords moderately high restraints and has the virtue of no mechanical linkages between the test weld and the stress measuring part of the system. However, the ratio of transverse bending moment to separating force is a nonadjustable feature of the "U" bar system. The "U" bar is an outgrowth of the keyhole plate used in earlier studies,[1] which was in turn a modification of the NRL slotted plate crack susceptibility test specimen.

The "U" bar has several signal advantages over the keyhole plate, including far more precise analytical interpretation of results, the possibility of using preheat, lower machining cost per specimen, and amenability to the use of run-on and run-off tabs. The vertical lever arm was designed to offer extreme, almost completely inelastic

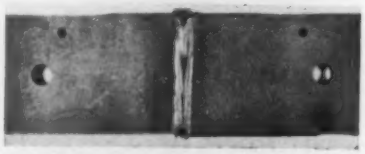

Fig. 7—Specimen for pure transverse loading with horizontal lever arms

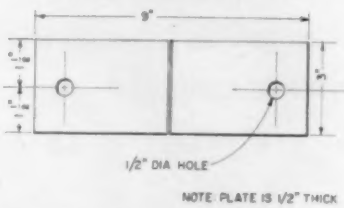

Fig. 8—Specimen design for pure transverse loading with horizontal lever arms

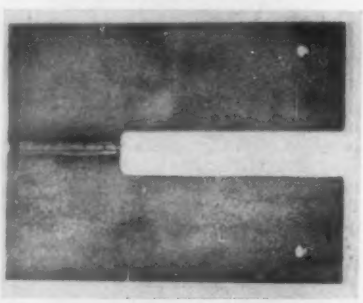

Fig. 9—9-in. moment arm specimen for horizontal lever arms

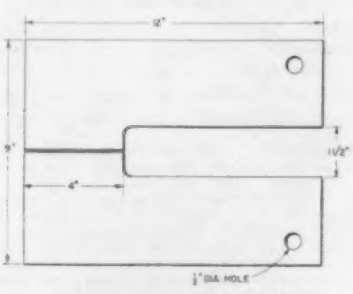

Fig. 10—9-in. moment arm specimen design for horizontal lever arms

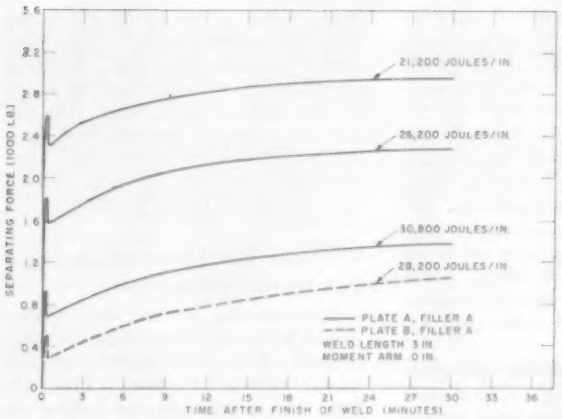

Fig. 11—Effect of power input on separating force

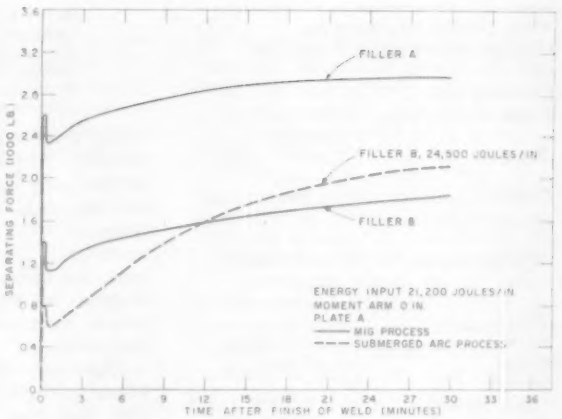

Fig. 12—Effect of filler and welding procedure on separating force

restraint to hindered contraction without any transverse bending moment. It is useful for measuring maximum stress levels and their rate of development in welds. The vertical lever arm apparatus has a fixed lever arm ratio giving the instrumented tensile members at the bottom of the machine a 10 to 1 mechanical advantage over the centroid of the weld. To date, the vertical lever arm has only been used in connection with manual shielded metal arc welding.

Most of the work was done using two heats of manganese-molybdenum armor plate of slightly differing chemistry, hardenability and (presumably) susceptibility to weld cracking. Low- and medium-carbon filler wires were used for automatic welding; plate and wire compositions are given in Table 1. Some manual welding was done in mild steel with E6010 and E6020 electrodes and on armor plate with $^1/_8$-in diam E10016 electrodes.

The types of test specimens used on the horizontal lever arm are shown in Figs. 7, 8, 9 and 10, one of which (Figs. 9 and 10) causes a bending moment as well as a separating force to be imposed upon the weld. The weld specimens used on the "U" bar and vertical lever arm apparatus are shown as mounted in Figs. 3, 4 and 6. On the horizontal lever arm apparatus, the specimen plates are affixed to the ends of the arms by means of 0.5-in. diam hardened-steel pivot pins, an arrangement which renders the bending moment imposed on the weld fully determinant.

On the "U" bar, the specimen plates must be welded into position for each run; after completion of the test, the specimens are flame cut from the "U" bar which can be calibrated and used for a large number of runs. Specimen plates on the vertical lever arm are also positioned by welding and flame cut after each test. Welded connections have been used to this extent to minimize backlash in mechanical joints. The auxiliary structural welds are located and dimensioned on both the "U" bar and the vertical lever arm apparatus so that there is no hazard of yielding or cracking in any but the test weld location.

All three sets of restraining apparatus were calibrated on a tensile testing machine. An analysis of the "U" bar as a curved beam,[2] checked by calibration, has led to the following equations for separating force, F, and bending moment, M, acting at the center of curvature of the "U" bar:

$$F = \frac{0.2865\ S_i - 0.562\ S_o}{0.2398} \quad (1)$$

$$M = \frac{2.72\ S_o - 0.96\ S_i}{0.2398} \quad (2)$$

where:

S_i = the absolute magnitude of the compressive stress measured

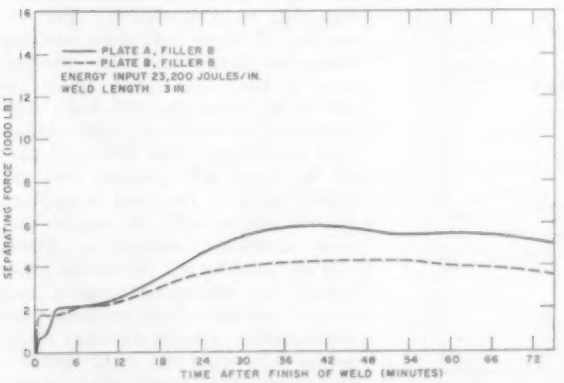
PLATE A, FILLER B
PLATE B, FILLER B
ENERGY INPUT 23,200 JOULES/IN.
WELD LENGTH 3 IN.
SEPARATING FORCE (1000 LB.)
TIME AFTER FINISH OF WELD (MINUTES)

Fig. 13—Effect of plate composition on separating force (Filler B)

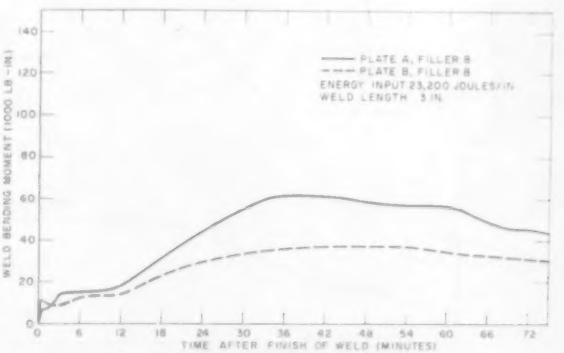
PLATE A, FILLER B
PLATE B, FILLER B
ENERGY INPUT 23,200 JOULES/IN.
WELD LENGTH 3 IN.
WELD BENDING MOMENT (1000 LB.-IN.)
TIME AFTER FINISH OF WELD (MINUTES)

Fig. 14—Effect of plate composition on bending moment (Filler B)

Table 2—Inert Gas Metal Arc (Consumable) Welding Procedure

Electrode size	1/16 in.
Angle of electrode	15° from vertical (forehand)
Gas shielding	70% argon – 30% helium
Contact tube height	7/8 in. from root-gap
Nozzle height	1 1/8 in. from root-gap
Joint geometry	30° single-bevel 1/4-in. land 1/16-in. root opening
Weld length	3 and 4 in.
Back-up strip	1/4-in. mild steel
Current	300–340 amp
Voltage	30–33 v
Travel speed	20–35 in./min
Wire feed rate	155–180 in./min

in psi at the inside strain gage location.

S_o = the absolute magnitude of the tensile stress measured in psi at the outside strain gage location.

Using these equations, the applied bending moment and separating force at any instant during or after welding can immediately be determined from pertinent strain gage readings. The two sets of lever arm apparatus are simple pivot devices in which the removable tensile members are calibrated individually.

Most of the results reported herein pertain to single pass metal-arc inert-gas (consumable) welds deposited with and without preheat, using a 30-deg single bevel joint preparation with 1/4 in. land and 1/16 in. root opening. Welding conditions are summarized in Table 2. In both sets of lever arm apparatus, a small preload was used to firmly seat all mechanical connections, and run-on and run-off tabs were used for all welds.

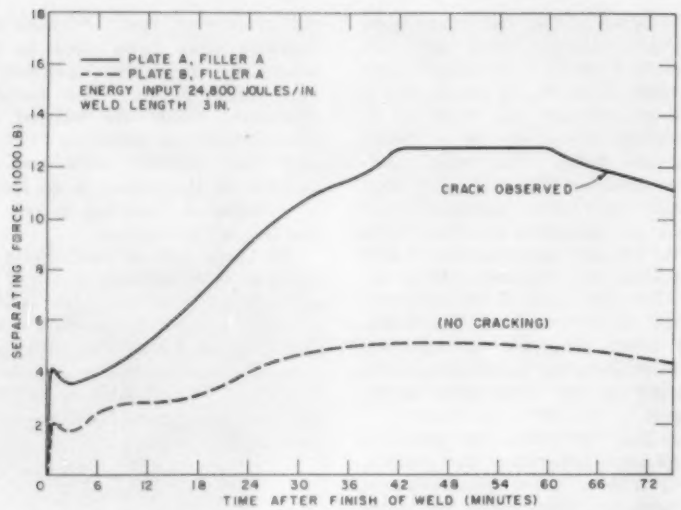

Fig. 15—Effect of plate composition on separating force (Filler A)

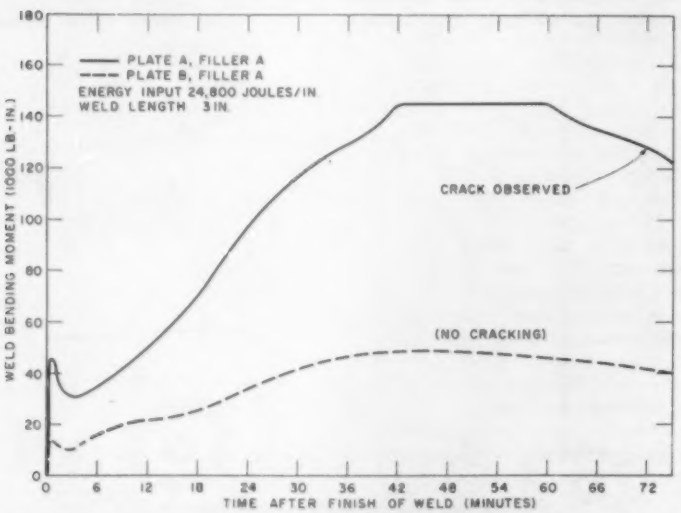

Fig. 16—Effect of plate composition on bending moment (Filler A)

Thermal Relationships in Hindered Contraction

The cooling in the weld under hindered contraction must be considered from two distinctly different points of view. The rate with which the weld and immediate heat-affected zone cool, establishes how rapidly the weld can become strong enough to sustain an elastic load. In addition, the weld cooling rate determines its metallurgical structure and strength, thereby influencing the maximum load which the weld can be expected to sustain elastically at room temperature.

The centerline cooling rate depends primarily upon conduction of the heat into the surrounding cold metal plate; it is little influenced by convection or radiation heat transfer from the plate to the air. On the other hand, the over-all rate with which the entire specimen loses heat to the surroundings establishes the rate of total solid contraction on the part of the plate being welded and is, therefore, an essential part of the loading mechanism involved. This over-all loss of heat from the plate takes place primarily by convection and radiation to the surroundings. (Redistribution of heat (temperature) within the plate does not effect important dimensional changes; it is only the heat that escapes entirely from the plate which is reflected in gross solid contraction.)

These concomitant and related cooling rates may, in a sense, be regarded as competitive. For example, if the centerline cooling rate was large and the over-all rate of heat loss quite small (as would be the case with high conductivity material or with radiation shielding), the hottest part of the weld will acquire strength before most of the load is applied, plastic strain will be minimized, and shrinkage distortion effects will be quite large. If, on the other hand, the centerline cooling rate is low (as with high preheat) and solid contraction effects make themselves felt while the weld metal is still very hot, substantial plastic flow obtains, and net shrinkage and final stresses are relatively low.

Thus, thermo-mechanical effects depend fundamentally upon the rate of over-all cooling as compared to the rate of centerline cooling in the subject weld.

Theoretical analyses of the heat conduction relationships which prevail during welding are usually directed to consequent metallurgical transformations. These transformations take place so early in the history of cooling that radiation and convection can be ignored with little error.[3] If, in addition to the heat conduction through the plate, transfer of heat from the surfaces of the plate to the surroundings is taken into account, the essential resulting mathematical relationships are as follows wherein the instantaneous temperature distribution across the weld is given by:

$$T - T_0 = \frac{1}{2t\sqrt{\pi K \rho C_p \theta}} \left(\frac{q}{V}\right) e^{-(x^2/4\alpha\theta + 2h\theta/t\rho C_p)} \quad (3)$$

where:

T = temperature at a distance, x, from the centerline of the weld, at time, θ, after the weld has been completed.
q = arc power.
V = arc travel speed.
ρ = density of the solid.
C_p = specific heat of the solid.
t = thickness of the plate.
h = heat transfer coefficient from the surface of the plate to the air.
K = thermal conductivity of solid.

Equation 3 is only valid after the weld has cooled substantially below its melting temperature. Differentiation of eq 3 gives, for the centerline cooling rate, $(dt/d\theta)_0$:

$$\left(\frac{dt}{d\theta}\right)_0 = \frac{(-)1}{2t\sqrt{\pi K \rho C_p \theta}} \left(\frac{q}{V}\right) \left(\frac{2h}{t\rho C_p} + \frac{1}{2\theta}\right) e^{-(2h\theta/t\rho C_p)} \quad (4)$$

Also, eq 3 can be integrated to represent the total heat content of the specimen plates at a given time, on the assumption that all heat leaving the plate does so by radiation and convection to the air. Carrying this through, and relating total heat loss to solid contraction:

$$S = \frac{h\alpha}{(t\rho C_p)^2} \left(\frac{q}{V}\right) e^{-(2h\theta/t\rho C_p)} \quad (5)$$

where:

S = the total transverse shrinkage rate (ft/hr) which a weld would exhibit in the absence of lateral external restraint (i.e., the rate with which the specimen plates would approach one another under conditions of free contraction).
α = coefficient of thermal contraction.

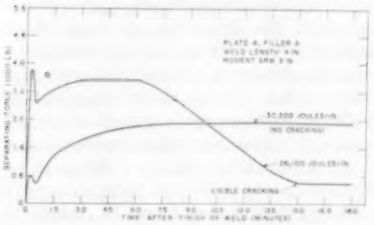

Fig. 17—Effect of power input on cracking

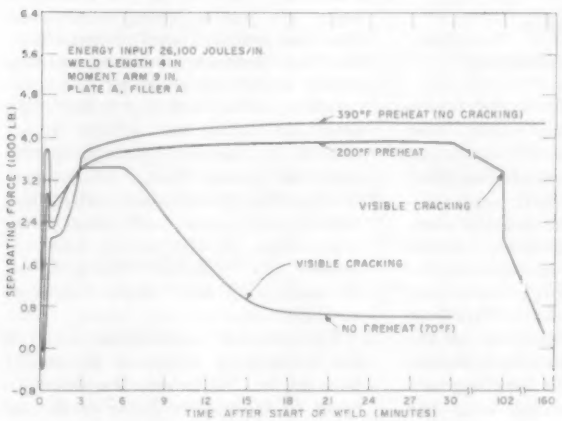

Fig. 18—Effect of preheat on cracking (Plate A)

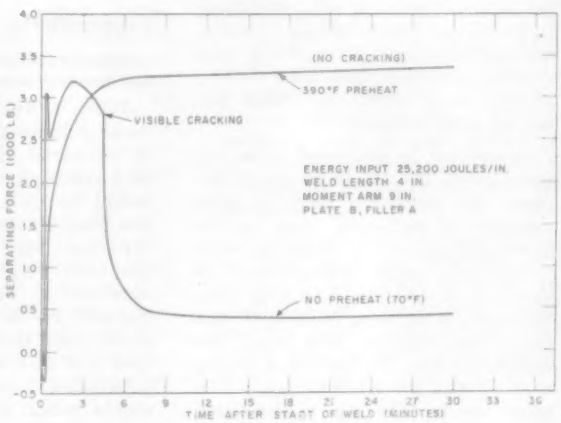

Fig. 19—Effect of preheat on cracking (Plate B)

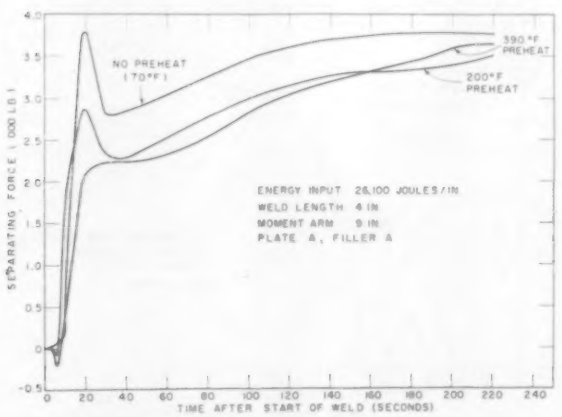

Fig. 20—Effect of preheat on dilatometric behavior of Plate A

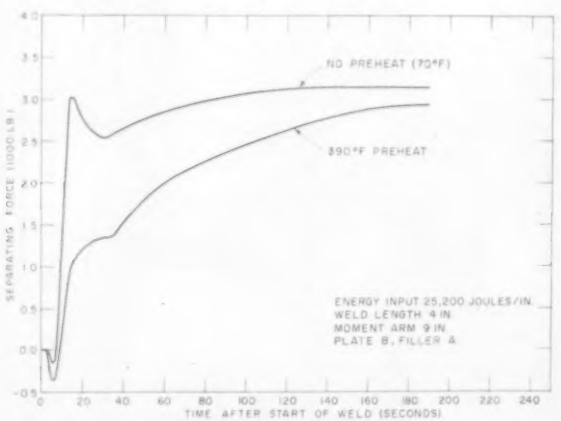

Fig. 21—Effect of preheat on dilatometric behavior of plate B

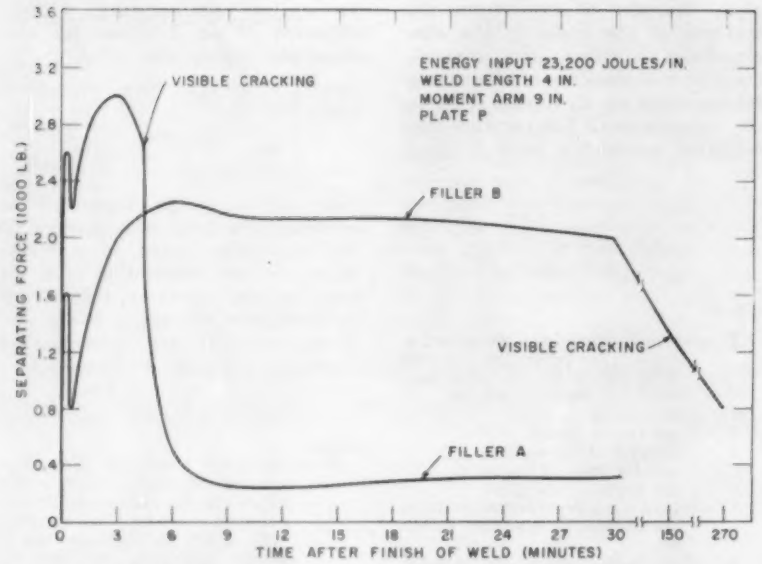

Fig. 22—Effect of filler on cracking

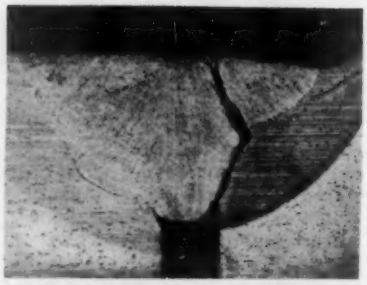

Fig. 23—Transverse macrosection of cracked weld. Etch: 2% Nital. Magnification: × 5

Equation 5 shows that the shrinkage rate decreases exponentially with time. It would, therefore, be expected that the rate of loading in restrained welds would follow a similar pattern. Except for discontinuities associated with elastic-plastic flow, this has been observed experimentally.

If preheat is employed, a second term must be added to eq 5, because the preheated plate is quite capable of radiating heat to its surroundings and undergoing solid contraction quite independent of the fact of welding. In any case, however, it is seen that both the centerline cooling rate and the shrinkage rate depend in a linear way on the arc energy input. In other words, the ratio of shrinkage rate to centerline cooling rate should be essentially independent of arc energy input.

Experimental Results

Factors Affecting Separating Force and Bending Moment

When a weld cools under transverse restraint, some plastic flow of the metal almost always occurs. As a result, shrinkages are less than would be obtained with free contraction. If this were not the case, the separating force measured across the weld would be exclusively determined by arc energy input and the stiffness of restraint. The data show that the composition of the filler and of the plate also influence separating forces and bending moments which the cooling weld can develop, because these factors influence the stress required to effect plastic flow. Figure 11 presents a series of curves determined with the horizontal lever arm apparatus. These curves show the effect of arc energy input and plate composition on separating force. Separating force decreases with increasing arc energy input and Plate B (which is slightly lower in carbon and alloy concentrations than Plate A) exhibits lower separating force than Plate A. In spite of the fact that both the load-carrying section of the weld and the total thermal contraction decrease with decreasing energy input, separating force increases. The higher cooling rate associated with low energy input results in higher local strengths and less plastic flow. Of interest also are the dilatometric inflections, which take place very soon after completion of the welds and are caused by volume changes associated with solid state transformations.

The general exponential shape of the stress-time curves is consistent with eq 5. However, the development of transverse loads continues

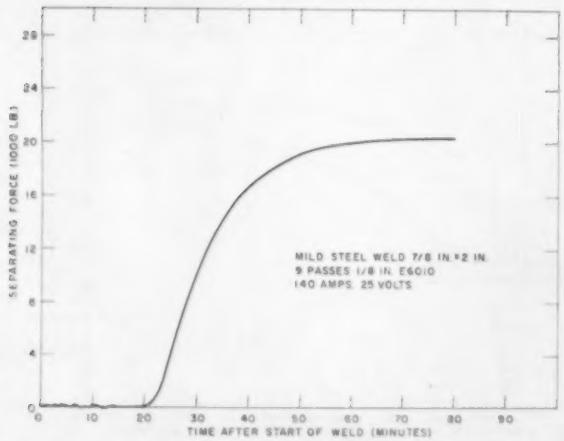

Fig. 24—Effect of multipass welding sequence on separating force in mild steel; continuous deposition

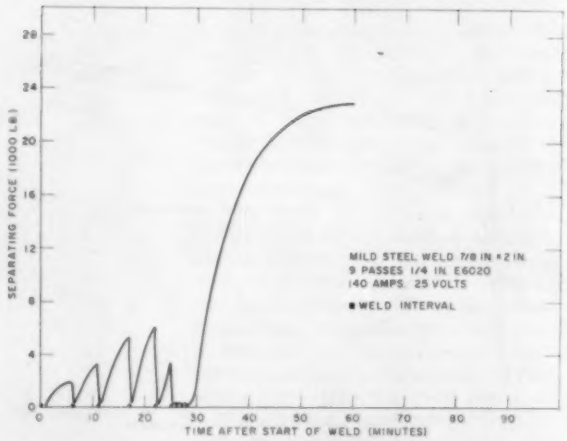
MILD STEEL WELD 7/8 IN.×2 IN.
9 PASSES 1/4 IN. E6020
140 AMPS. 25 VOLTS
■ WELD INTERVAL
SEPARATING FORCE (1000 LB.)
TIME AFTER START OF WELD (MINUTES)

Fig. 25—Effect of multipass welding sequence on separating force in mild steel; short interpass time

for more than 30 min after welding, long after the weld has reached room temperature.

The chemistry of the filler metal has a pronounced influence on separating force, especially in a system where the smallest load-carrying cross section is the fusion zone, itself. A medium-carbon filler sustains higher separating forces than a low carbon filler as shown in Fig. 12. Comparison of the submerged-arc process with the inert-gas-shielded metal-arc process in Fig. 12 reflects a process difference with respect to the ratio of centerline cooling rate to over-all cooling rate. The slag cover in submerged-arc welding has relatively little influence on conduction within the plate and, therefore, on the centerline cooling rate of the weld. However, the slag cover does slow the transfer of heat from the surface of the plate to the air. As a consequence, the weld has more of a chance to "get strong" before the full contraction strain is imposed. As a result, the ultimate loads are higher although the initial rate of loading is somewhat reduced by the shielding slag cover.

Data collected under the more severe restraint imposed by the "U" bar and plotted in terms of separating force and bending moment in Figs. 13 through 16 show substantially higher loads but the same pronounced influences of plate and filler compositions as in Figs. 11 and 12.

Factors Affecting Cracking

Arc energy, preheat and filler and plate compositions influence the incidence and time of cracking. Perhaps the most important over-all observation which can be made, based on data collected on all three types of apparatus, is that a transverse bending moment has been found prerequisite to cracking in short welds(up to 4 in.). Pure transverse restraint never induced cracking.

Low energy input favors cracking as shown in Fig. 17. The subtle development of a crack, such as that represented in Fig. 17, is of interest. Visible cracking was almost always preceded by a decrease in separating force, either on the "U" bar or the horizontal lever arm apparatus. As a part of the experimental routine, it has become possible to predict failure from the stress sensing elements well before any visual evidence of a crack develops.

The "U" bar evidenced its potential as a device for assessing crack susceptibility by distinguishing between Plate A, which exhibited cracking more than 1 hr after welding with medium-carbon filler A, and Plate B which did not crack with the same filler—Figs. 13, 14, 15 and 16.

Low preheat has the effect of increasing the time delay before cracking, while high preheat has the anticipated effect of eliminating cracking altogether—Figs. 18 and 19. The first 200 sec of Figs. 18 and 19 are shown on expanded scales in Figs. 20 and 21 and illustrate that dilatometric inflections, which take place within the first 30 sec, are progressively reduced by preheat. Figures 20 and 21 also depict slight expansion effects (negative separating force) immediately after welding; these increase somewhat with preheat. Although the lever arm apparatus was not designed to measure unanticipated compressive loads in the weld, this behavior appears to be caused by the feedback of heat by conduction from the run-off tab after the weld has become barely solid enough to support a slight compressive load and push against the preloading device.

When conditions are deliberately adjusted to induce cracking, the medium-carbon filler causes cracking to take place earlier than does the low-carbon filler—Fig. 22. Also, comparison of Figs. 13 and 14 with Figs. 15 and 16—based on "U" bar determinations—shows that medium-carbon filler is more likely to induce cracking than is low-carbon filler. Since cracking is always initiated in heat-affected zones of welds, the conclusion is that filler alloys which exhibit high strengths as deposited tend to favor cracking by imposing high loads on the heat-affected zone.

The transverse macrosection of a typical crack is shown in Fig. 23. The extent of cracking depends on the elasticity of the restraining system. The horizontal lever apparatus, being more elastic than the "U" bar, absorbs greater deflections during contraction. Upon cracking the deflections feed back to open and propagate the cracks. Cracks formed on the "U" bar are very fine because deflections are small, and relief of stresses by cracking is accompanied by very little movement.

That substantial changes in loading take place and cracking often initiates long after a weld has reached room temperature clearly indicate that delayed, stress-induced solid state transformations have important bearing on re-

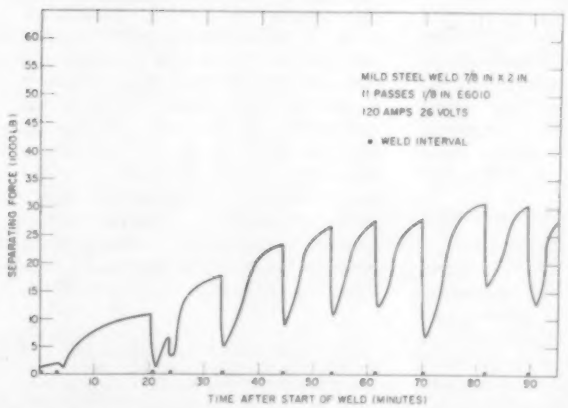
MILD STEEL WELD 7/8 IN X 2 IN
11 PASSES 1/8 IN. E6010
120 AMPS 26 VOLTS
• WELD INTERVAL
SEPARATING FORCE (1000 LB)
TIME AFTER START OF WELD (MINUTES)

Fig. 26—Effect of multipass welding sequence on separating force in mild steel; long interpass ime

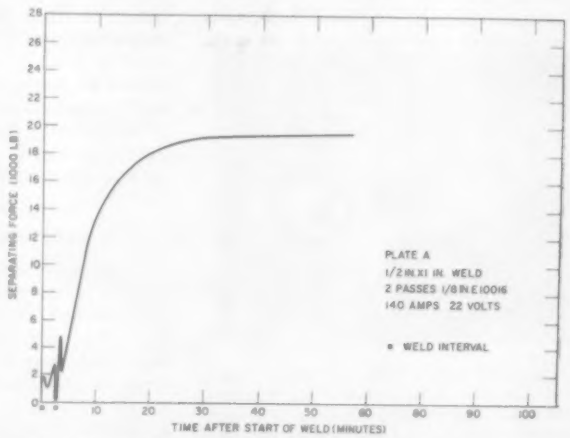

Fig. 27—Effect of weld length on separating force in armor plate (1-in. weld)

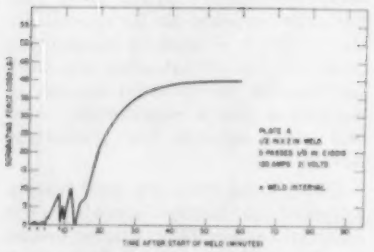

Fig. 28—Effect of weld length on separating force in armor plate (2-in. weld)

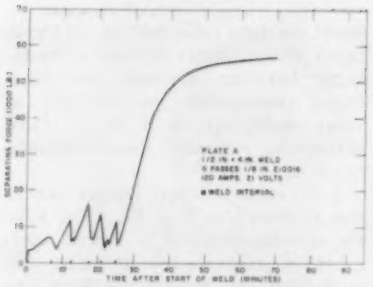

Fig. 29—Effect of weld length on separating force in armor plate (4-in. weld)

sponses to hindered contraction. These can only be clarified by exhaustive comparison of microstructures which result with and without restraint; very little study has to date been given the effect of hindered contraction on phase changes.

Multipass Manual Shielded-arc Welding (Vertical Lever Arm Apparatus)

Separating force vs. time histories of three multipass welds in $^{7}/_{8}$-in. thick mild steel plate are shown in Figs. 24, 25 and 26, and clearly indicate the effect of time between passes on self-annealing and peak load. In Fig. 24 is shown the separating force behavior when all passes are deposited in as rapid sequence as possible, with the interval between passes just long enough to permit chipping. When the interval between passes is increased somewhat, forces build up and are completely relieved by the heat of subsequent passes so long as the interval between passes is not too long—Fig. 25. With this procedure, the total shrinkage and peak load ultimately reached are slightly higher than for nearly continuous welding. Still further increase in the interval between welds creates a situation in which full stress relief is not achieved by subsequent passes; the load buildup is somewhat cumulative, and ultimate loads and shrinkages reached are appreciably higher than with closely sequenced welds.

Three manual shielded-metal-arc welds (1, 2 and 4-in. long, respectively) were also made on $^{1}/_{2}$-in. thick armor plate—Figs. 27, 28 and 29. Under the very severe but purely transverse restraint imposed by the vertical lever arm apparatus, the transverse loads developed by high strength materials are high. The rate with which loads develop between passes is higher than with mild steel, and these loads are less likely to become fully stress relieved by subsequent passes. The peak load increases systematically with the length of the weld, developing about 20,000 lb per lineal in.—or 40,000 psi on $^{1}/_{2}$-in. thick plate—for short welds. The 4-in. weld in Fig. 29 was less highly stressed and shrank more than the 1- and 2-in. welds, since even the 12-in. 105-lb/ft wide-flange beams exhibited some elastic deflection under the 30 ton transverse load.

Conclusions

1. A weld which cools under conditions of hindered contraction develops transverse loads at a rate which decreases with time, in conformance with the rate of heat transfer from the plate to the environment.

2. The separating force which accompanies hindered contraction generally increases with the strength and/or hardenability of filler and plate materials.

3. With hardenable materials, over the range studied, separating force increases with decreasing arc-energy input, in spite of the fact that total contraction decreases and fusion zones become smaller in cross section. This is opposite to the behavior which would be expected with mild steel.

4. Factors which increase separating force usually favor initiation of cracking or decrease the time required for cracking.

5. Transverse bending (tearing) moments appear prerequisite to cracking. Pure lateral restraint, even if very severe, does not induce cracking.

6. Preheat reduces the incidence of cracking and increases the time delay associated with cracking. Preheat also reduces dilatometric inversion, which is observed immediately after welding and which relates to solid state transformations brought about by cooling.

Acknowledgment

The authors wish to express their sincere appreciation to the Department of the Army, Ordnance Corps, whose support through the Watertown Arsenal Laboratories made this research possible, and also to William P. Hatch and Carl Hartbower of Watertown Arsenal Laboratories whose timely suggestions and cooperative interest contributed materially to the success of the investigation.

Bibliography

1. White, S. S., Moffatt, W. G., Adams, C. M., Jr., "Dynamic Measurement of Stress Associated with Weld Cracking," THE WELDING JOURNAL, **23** (4), Research Suppl., 185s to 192s (April 1958).

2. Den Hartog, J. P., *Advanced Strength of Materials*, McGraw-Hill Book Co., Inc. (1952).

3. Adams, C. M., Jr., "Cooling Rates and Peak Temperatures in Fusion Welding," THE WELDING JOURNAL, **37**, (3) Research Suppl., 210-s to 215-s (1958).

Pressure Butt Welding of Steel Pipe Using Induction Heating

The details of original experimentation are presented so as to fill gaps in existing information on the metallurgical and technical aspects of induction heating as used for welding

BY S. G. HARRIS

SUMMARY. Experiments in solid-phase bonding of boiler tubing using induction heating were carried out. Results indicate that this is a satisfactory method of joining pipes and has considerable advantage over some of the other butt welding processes. The present paper deals with the metallurgical and mechanical aspects of this joining process; especially such operatives as temperature, pressure, heating conditions and inert-gas shielding.

Introduction

Considerable interest from time to time has been shown in pressure butt welding of pipes. It has been realized that it might provide an economically fast and convenient method of joining pipes with the possibility of obtaining an interior surface free from weld flash, backing-up rings, etc., which, in many existing methods of pipe welding, present undesirable fluid-flow conditions inside the pipe. Considerable previous work has been done on processes to evolve such a welding method.

A number of processes for butt welding of pipes have been developed using oxyacetylene or other gas mixtures as a source of heating. Some of these have proved successful and are being used commercially.[1-3] The major difficulty, when gas heating is used, appears to be in controlling the gas flame and in obtaining a sufficiently rapid heating rate to prevent excessive grain growth. Elaborate gas pressure regulating apparatus has been evolved,[4,5] but difficulty has still been experienced since the wide heating zone often leads to buckling when pressure is applied. Fast heating rates often cause weld surface melting and oxidation, resulting in extremely variable properties.

Low-frequency induction heating for butt welding has several advantages over other heating methods. It is a well developed process, susceptible to reasonable control and reproducibility. It is also a very rapid heating process allowing temperatures up to 2500° F to be reached in a few seconds. Rapid heating rates reduce the amount of surface oxidation while allowing faster welding. Since induction heating at low frequencies is not restricted to the surface layers, a more uniform heating can be obtained with less fear of surface melting, than by purely external heating methods. Finally, the heated zone can be confined by appropriate inductor design, thus avoiding the risk of the pipe buckling during upsetting.

The object of the work described here was to use induction heating to evolve a rapid and efficient method of producing welds which possessed (*a*) the necessary mechanical properties and (*b*) an interior weld configuration free from obstructions which would hamper gas or liquid flow.

Experimental Apparatus

The present work was carried out using a 100 kva, 10,000 cycle motor-generator set and an inductor of commercial design—Figs. 1 and 2. The majority of the tests were done on $2^1/_2$-in. Schedule 40 pipe (with a normal 2.875-in. OD) in an inductor having a 3.325-in. ID, thus giving an air gap of 0.225 in. The hydraulic press was capable of giving loads from 0 to 20,000 lb and was fitted with an electrically controlled valve allowing movements "up," "down" and "hold." Thus all pressures were on press-button control allowing precise timing of upsets, etc. The extent of upset could be limited by an adjustable microswitch

Fig. 1—View of master heating station, hydraulic upsetting press and ancillary equipment

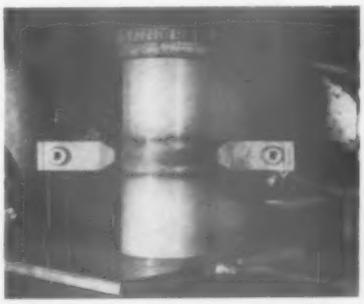

Fig. 2—A welded pipe in the press with one-half of the split-ring inductor removed to show the air gap; the plates on the top of the pipe are packing pieces used to bring the weld plane coincident with the mid-plane of the inductor

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which was preset for each test.

Temperatures were measured by a thermocouple which was resistance welded to the interior pipe wall about $^1/_{32}$ in. from the abutting pipe face. The signal from the thermocouple was fed to a continuous strip-chart temperature recorder. Alternating-current pickup was filtered out by placing a condenser across the thermocouple terminal.

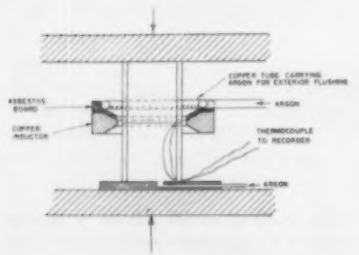


Fig. 3—Diagram of arrangement for gas shielding

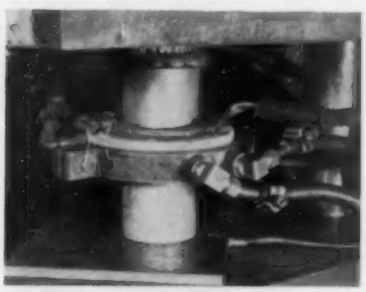


Fig. 4—Press closed with gas-shielding apparatus in place

Gas shielding was effected by running argon into the interior of the pipe through a false bottom plate and surrounding the joint area with a copper tube containing $^1/_{16}$-in. holes at $^1/_4$-in. spacing as shown in Figs. 3 and 4. This arrangement ensured an ample flow of gas to both the interior and the exterior of the weld joint.

Weld Testing Procedure

Evaluation of the mechanical properties of the welds was made by sectioning the pipe as shown in Fig. 5. This provided four pairs of bend test coupons, one metallographic sample, and one piece from which a flat tensile sample was machined with 2 in. gage length and 0.1- x 0.5-in. section. The remaining pieces were sometimes used for experiments on the effects of heat treatment which provided guidance in planning future welding programs.

The bend-test coupons were subjected to 180 deg bending around a 1-in. radius (4 × wall thickness). Each pair was tested with one coupon having the interior surface in tension, and the other having the exterior surface in tension.

Pairs of coupons numbered 1 and 3 were bent with the weld reinforcement left on, while the pairs numbered 2 and 4 were bent after the weld reinforcement had been removed from both surfaces.

Experimental Procedure

Three types of pipe were used in this investigation: plain carbon mild steel pipe denoted by the prefix letter C in specimen numbering, chromium-molybdenum boiler tubing denoted by the prefix letters CM, and 18/8 stainless steel tubing denoted by the prefix letter S. The stainless steel and chromium-molybdenum pipe was $2^1/_2$-in. Schedule 40 pipe (roughly $^1/_4$-in. wall), while the plain carbon pipe was in two sizes: $1^1/_2$-in. Schedule 80 pipe (roughly $^1/_4$-in. wall) and $2^1/_2$-in. Schedule 80 pipe (roughly $^5/_{16}$-in. wall).

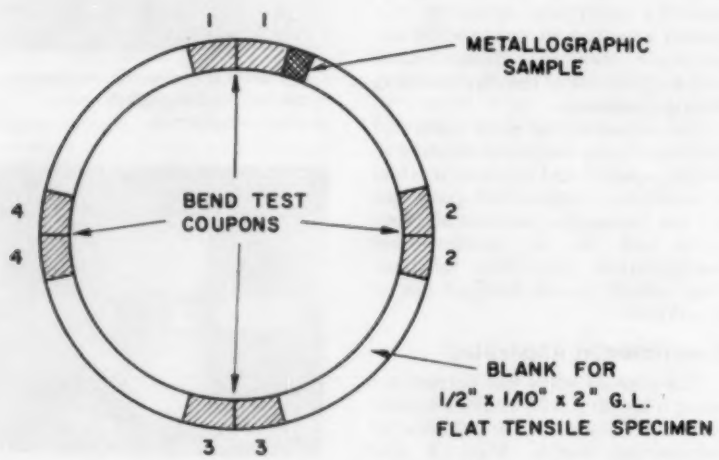
All pipes were cut to $3^1/_2$-in. lengths with square end faces. Prior to welding, the pipes were degreased for $^1/_2$ hr in a trichlorethylene vapor degreaser. Following this, the abutting surfaces were either scratch brushed or were given a small grinding cut with a number 80 grit abrasive. Although some good results were obtained with scratch brushing, it was discarded in later tests in favor of grinding since brushing had a tendency to round off the specimen edges, thus giving rise to an internal notch which was thought to be deleterious to the bend test properties. Welding was programmed to ensure that no more than 5 min elapsed between final grinding or scratch brushing and welding.

When argon was used, it was allowed to flow into the interior of the pipes at a rate of about 6.5 cfh (3 liters per min) for at least 1 min prior to closing the press. Thereupon the interior and the exterior flushing ring were on a common gas line which thereby left the interior of the pipe under a very slight positive pressure of argon.

Two heating cycles were devised to give a temperature in the pipe of 2500° F in either 10 or 35 sec. The optimum coupling was attained by suitably adjusting the transformer taps and circuit capacitance. Once the voltage settings for the heating cycle had been determined, subsequent runs were carried out on a setting of "no-load voltage" and a timed heating cycle. Thus identical heating conditions could be repeated throughout a series of tests. Apart from experimental heat treatments which were done on extra pieces of sectioned pipe, all heat treatments were carried out by induction heating with the pipe samples in position for welding.

Two general types of test were done:

1. Those carried out at constant pressure; i.e., the pressure was on at the start of heating and upsetting occurred when the metal had become sufficiently heated to deform.



WELD REINFORCEMENT REMOVED FROM BEND TEST COUPONS No. 2 AND No. 4

Fig. 5—Method of sectioning welded pipe for testing

Table 1—Experimental Welding Data and Results for 2¼-in. Chromium-molybdenum Pipe

Specimen No.	Heating cycle, sec	Upset, in.	Pressure program	Pressure, psi	Shielding gas	Heat treatment	Ultimate tensile strength, 1000 psi	Yield point, 1000 psi	Elongation, %	Bend tests: Pass	Bend tests: Failures, degrees of bend
CM-1	35	1/4	C	2,000	None	None	80.6	...	12.0	4	45-45-10-5
CM-2	35	1/4	C	4,000	None	None		Not tested		1	60-80-80-30-60-30-70
CM-3	35	1/4	C	6,000	None	None		Not tested		3	90-80-5-120-20
CM-4	35	1/4	C	8,000	None	None		Not tested		2	80-20-20-10-90-5
CM-5	35	1/4	C	10,000	None	None		Not tested		1	20-20-10-5-90-20-5
CM-6	35	1/4	C	12,000	None	None		Not tested		0	10-90-5-160-10-30-5-30
CM-7	35	1/4	C	14,000	None	None		Not tested		4	90-10-30-10
CM-10	18	1/4	C	14,000	None	None		Not tested		0	5-5-5-5
CM-11	19	1/4	C	10,000	None	None		Not tested		0	5-5-5-5
CM-12	19	1/4	C	10,000	None	None		Not tested		0	5-5-5-5
CM-13	23	1/4	C	6,000	None	None		Not tested		0	20-45-30-45
CM-20	10	1/4	C	2,000	None	None	81.0	61.6	13.0	7	90
						10 min at 1800° F[a]		Not tested		2	.....
CM-21	10	1/4	C	2,000	None	None	79.6	62.8	13.0	3	100-90-90-90-10
						1 hr at 1750° F, cooled + 1 hr at 1250° F[a]	69.2	47.7	22.0	2	.....
CM-22	10	1/4	C	6,000	None	None	92.8	72.0	13.0	3	45-90-40-90
						1 hr at 1750° F, cooled + 1 hr at 1250° F[a]	70.2	...	28.0	2	.....
CM-23	10	1/4	C	10,000	None	None		Not tested		3	90-90-90-20-90
CM-26	10	1/4	C	6,000	None	5 min at 2450° F	96.2	76.8	3.0	4	40-50-90-100
CM-27	10	1/4	C	6,000	None	2 min at 2450° F		Not tested		5	120-170-90
CM-28	10	1/4	C	6,000	None	30 sec at 2450° F		Not tested		3	90-120-70-60-30
CM-29	35	1/4	C	2,000	None	2 min at 2450° F	86.2	71.6	7.5	1	45-60-80-90-10-5
CM-30	35	1/4	C	2,000	None	5 min at 2450° F	91.6	59.4	6.0	3	110-5-160-5
CM-31	35	1/4	C	10,000	None	Cycled 3 times from 1800 to 800° F	81.8	71.6	10.0	4	45-45-70-90
CM-50	10	1/4	C	2,000	None	5 min at 1600° F		Not tested		1	60-25-80-10-40-20-120
CM-51	10	1/4	C	2,000	None	10 min at 1600° F		Not tested		1	30-45-45-45-10-5-45
CM-56	10	1/4	C	2,000	Argon	10 min at 1800° F	80.2	61.6	9.5	3	120-60-100-20-45
CM-57	10	1/4	C	4,000	Argon	10 min at 1800° F	84.4	57.0	8.0	3	160-70-45-30-45
						1 hr 1750° F, cool + 1 hr at 1250° F	69.4	48.7	18.0	2	.....
CM-58	10	1/4	C	2,000	Argon	None	80.2	65.8	12.0	4	120-60-70-120
						1 hr at 1750° F, cooled 1 hr at 1250° F[a]	70.6	48.9	31.0	2	.....
CM-59	10	1/4	C	14,000	Argon	None	90.4	67.0	13.5	4	30-20-10-10
						1 hr at 1750° F, cooled + 1 hr at 1250° F[a]	70.0	...	30.0	2	.....
CM-60	10	1/16	D	10,000	Argon	10 min at 1800° F		Not tested		1	80-30-90-160-45-20-60
CM-61A	10	1/4	C	2,000	Argon	None	83.5	62.8	14.0	5	30-30-60
CM-62A	10	1/4	C	2,000	Argon	10 min at 1800° F		Not tested		6	30-60
CM-63A	10	1/16	C	2,000	Argon	10 min at 1800° F	86.8	56.0	6.0	2	60-60-90-30-60-60
						Temper 1/2 hr at 1250° F[a]	77.2	62.0	16.0	1	110
CM-64A	10	1/16	D	14,000	Argon	10 min at 1800° F	82.4	58.4	5.5	3	90-90-60-60-40
						Temper 1/2 hr at 1250° F[a]	75.4	64.2	12.0	1	120
CM-65A	10	1/8	D	14,000	Argon	10 min at 1800° F	84.4	58.2	9.0	2	60-120-90-45-40-60
						Temper 1/2 hr at 1250° F[a]	74.4	60.8	17.0	1	90
CM-66A	10	1/4	D	14,000	Argon	10 min at 1800° F	84.2	51.0	12.0	7	80
						Temper 1/2 hr at 1250° F[a]	73.0	58.5	17.0	2	.....
CM-67A	10	1/2	D	14,000	Argon	10 min at 1800° F	80.6	53.2	13.0	8	.....
						Temper 1/2 hr at 1250° F[a]	75.4	57.0	19.0	2	.....
CM-68A	10	1/4	C	2,000	Argon	10 min at 1800° F	85.0	58.6	7.0	7	80
						Temper 1/2 hr at 1250° F[a]	75.8	59.6	20.0	2	.....
CM-69A	10	1/8	D	14,000	Argon	10 min at 1800° F	80.0	57.6	10.0	5	110-90-60
						Temper 1/2 hr at 1250° F[a]		Not tested		3	90
CM-62B	10	1/4	D	14,000	Argon	10 min at 1250° F		Not tested		8	.....
CM-63B	10	1/4	D	14,000	Argon	Cool + 10 min at 1250° F		Not tested		7	60
CM-64B	10	1/4	D	14,000	Argon	Cool + 30 min at 1250° F		Not tested		8	.....
CM-65B	10	1/4	D	14,000	Argon	5 min at 1800° F + 10 min at 1250° F		Not tested		7	90
CM-66B	10	1/4	D	14,000	Argon	5 min at 1800° F, cool + 10 min at 1250° F		Not tested		7	90
CM-67B	10	1/4	D	14,000	Argon	5 min at 1800° F, cool + 30 min at 1250° F		Not tested		7	110
CM-68B	10	1/4	D	14,000	Argon	2 min at 2450° F + 10 min at 1250° F		Not tested		6	90-120
CM-69B	10	1/4	D	14,000	Argon	2 min at 2450° F + 10 min at 1800° F, cool + 10 min at 1250° F		Not tested		8	.....
CM-70	10	1/4	D	14,000	Argon	2 min at 2450° F, cool + 10 min at 1250° F		Not tested		8	.....
CM-71	10	1/4	D	14,000	Argon	2 min at 2450° F, cool + 30 min at 1250° F		Not tested		7	90
CM-72	10	1/4	D	14,000	Argon	2 min at 2450° F + 5 min 1800° F + 10 min at 1250° F		Not tested		7	120

(Continued on next page)

(Continued)

Table 1—Experimental Welding Data and Results for 2 1/2-in. Chromium-molybdenum Pipe

Specimen No.	Heating cycle, sec	Upset, in.	Pressure program	Pressure, psi	Shielding gas	Heat treatment	Ultimate tensile strength, 1000 psi	Yield point, 1000 psi	Elongation, %	Bend tests: Pass	Bend tests: Failures, degrees of bend
CM-73	10	1/4	D	14,000	Argon	2 min at 2450° F + 5 min at 1800° F, cool + 10 min at 1250° F	Not tested			6	130-130
CM-74	10	1/4	D	14,000	Argon	Quench in cold water + 30 min at 1250° F	Not tested			8	.....
CM-75	10	1/4	D	14,000	Argon	2 min at 2450° F, quench in cold water + 30 min at 1250° F	Not tested			8	.....
CM-77	10	1/4	D	14,000	Argon	10 min at 1250° F	Not tested			8	.....
CM-78	10	1/8	D	14,000	Argon	10 min at 1250° F	Not tested			8	.....
CM-79	10	1/16	D	14,000	Argon	10 min at 1250° F	Not tested			7	90
CM-80	35	1/8	C	2,000	Argon	10 min at 1250° F	Not tested			3	5-20-5-5-20
CM-81	35	1/8	C	6,000	Argon	10 min at 1250° F	Not tested			4	20-60-90-40
CM-82	35	1/16	C	6,000	Argon	10 min at 1250° F	Not tested			3	30-30-20-20-20

[a] Designates tests carried out on extra coupons from original welded pipe sample.

2. The dual pressure cycle tests in which only a slight pressure sufficient to keep the abutting ends together was applied initially and the upsetting pressure was applied at the end of the heating cycle.

Experimental data and test results are presented in Tables 1 to 3. The first seven columns give the details of welding; specimen number, heating cycle, upset value, pressure program, pressure, and other details such as gas shielding and heat treatment. Ultimate tensile strength, yield point and elongation values appearing in the next three columns were obtained from the flat tensile specimen results. The results of bend tests are given in the final two columns. The first column of the bend test results gives the number of coupons which were successfully bent through 180 deg without failing, while the second column gives the approximate angles of bending at which fracture occurred in coupons which failed to bend a full 180 deg. The bend test proved to be the most valuable criterion in judging weld quality.

Experimental Results

Chromium-molybdenum Alloy Steel Pipe

Initial experiments were made on Cr-Mo pipe. Tests were made without gas shielding in which temperature and pressure were varied on a 35 sec heating cycle to explore the general features of induction butt welding. Welds were made using a constant pressure cycle and pressures were varied from 2000 to 14,000 psi, using a 1/4-in. total upset; i.e., 100% pipe wall thickness. Under these conditions upsetting occurred at successively lower temperatures as pressure was increased (specimens CM-1 to CM-7, Table 1), but the tests were run through the full heating cycle—that is, up to a temperature of 2500° F. A second series (specimens CM-10 to CM-13) were carried out under the same conditions except that the heat was shut off as soon as upset had taken place (at temperatures as low as 1900° F for the tests done at 14,000 psi pressure).

The bend test results indicate that neither series produced very acceptable results, but it is apparent that the samples which were heated throughout the entire heating cycle to 2500° F were superior to the second series welded at lower temperature. It also appears from

Table 2—Experimental Welding Data and Test Results for 1 1/2 in.- (C-1 to C-9) and 2 1/2 in.- (C-20 to C-36) Plain Carbon Pipe

Specimen No.	Heating cycle, sec	Upset, in.	Pressure program	Pressure, psi	Shielding gas	Heat treatment	Ultimate tensile strength, 1000 psi	Yield point, 1000 psi	Elongation, %	Bend tests: Pass	Bend tests: Failures, degrees of bend
C-1	20	1/4	D	14,000	Argon	None	60.8	46.2	28.0	6	...
C-2	10	1/4	D	14,000	Argon	2 min at 1800° F	68.2	43.1	21.0	6	...
C-3	10	1/8	D	14,000	Argon	2 min at 1800° F	59.0	51.6	20.0	6	...
C-4	10	1/16	D	14,000	Argon	2 min at 1800° F	61.4	45.7	24.0	6	...
C-5	10	1/8	C	14,000	Argon	2 min at 1800° F	62.2	45.4	24.0	6	...
C-6	10	1/8	C	28,000	Argon	2 min at 1800° F	67.4	47.6	20.0	6	...
C-7	10	1/16	C	14,000	Argon	2 min at 1800° F	60.4	43.9	31.0	6	...
C-8	10	1/8	D	14,000	None	2 min at 1800° F	61.6	46.3	25.0	6	...
C-9	10	1/16	D	14,000	None	2 min at 1800° F	63.0	46.5	22.0	5	90
C-20	15	1/4	C	2,000	None	1 min at 2450° F	Not tested			7	30
C-22	10	3/16	C	2,000	None	5 min at 1800° F	Not tested			5	90-80-100
C-23	10	3/16	C	10,000	None	5 min at 1800° F	Not tested			7	45
C-24	10	3/32	C	2,000	Argon	5 min at 1800° F	Not tested			6	90-90
C-25	10	3/16	D	10,000	Argon	5 min at 1800° F	Not tested			8	...
C-26	10	3/16	D	10,000	Argon	30 sec at 2200° F	Not tested			8	...
C-27	10	3/16	D	10,000	Argon	None	Not tested			6	90-90
C-28	10	3/16	D	10,000	Argon	1 min at 2450° F	Not tested			8	...
C-29	10	1/8	D	10,000	Argon	5 min at 1800° F	Not tested			8	...
C-30	10	1/8	D	10,000	None	1 min at 2450° F	Not tested			8	...
C-32	35	3/16	D	10,000	Argon	None	Not tested			8	...
C-33	35	3/16	D	10,000	Argon	None	Not tested			8	...
C-34	35	3/16	C	2,000	Argon	None	Not tested			8	...
C-36	35	1/16	C	2,000	Argon	None	Not tested			7	100

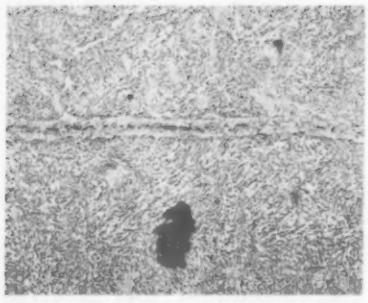


Fig. 6—Gross oxidation at interface of welded sample; ×200 (reduced 50% on reproduction)

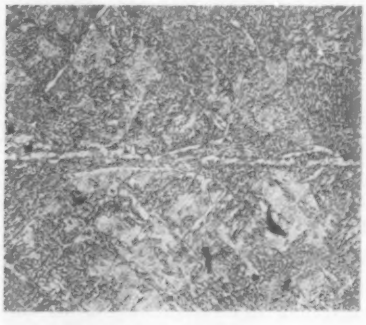


Fig. 7—Line of ferrite grains making interface at mid-plane of weld; × 200 (reduced 50% on reproduction)

samples CM-1 to CM-7 that the pressure under which welding is carried out has very little, if any, influence on the quality of the weld.

Metallographic examination was done on a few of these samples. Figure 6 shows the considerable oxidation that occurred in the weld plane. Such gross oxide particles were more prevalent near the edge of the weld plane and extended varying distances toward the center of the

Fig. 8—Ferrite grains showing discrete particles in the weld plane; × 1000 (reduced 50% on reproduction)

pipe. In the center of the weld plane, gross oxide particles were generally absent, but the weld plane was distinguished by a line of fine ferrite grains as in Fig. 7. At high magnification as in Fig. 8 these ferrite grains showed a line of discrete round spots which presumably are spherical oxide particles. The ferrite grains presumably are the result of decarburization of the abutting surfaces during heating. The matrix structure in these photomicrographs bears very little resemblance to that of the annealed structure in Fig. 9. This suggested that some further heat treatment might be beneficial in improving the weld quality.

Figure 10 is a photomicrograph of a sample welded at a lower temperature and again reveals severe oxidation in the weld plane. Very little recrystallization has occurred across the weld interface and, indeed, even the matrix appears generally similar to the normalized structure of Fig. 9, suggesting that very little material had transformed during the short time at high temperature.

A further series of parallel ex-

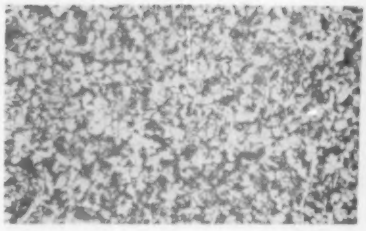


Fig. 9—Normalized structure of Cr-Mo pipe; × 200 (reduced 50% on reproduction)

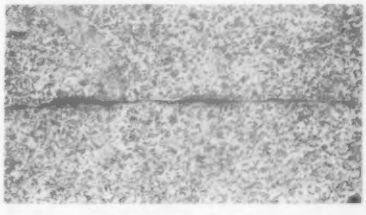


Fig. 10—Weld zone of a specimen welded at high pressure and low temperature; × 200 (reduced 50% on reproduction)

periments was made using a 10 sec heating cycle. By reducing the time at high temperature, it was hoped to cut down the amount of oxidation of the welding surfaces. The results of samples CM-20 to CM-23 show that only slight improvement was effected over those samples welded on the 35 sec heating cycle.

The poor bend test properties, along with the metallographic evidence of oxide and fine ferrite grains in the weld interface, suggested experiments which would bring about increased recrystallization and grain growth across the interface, and consequently a stronger bond. To this end, a series of samples was welded and subsequently held at

Table 3—Experimental Welding Data and Results for 2½-in. Stainless Steel Pipe

Specimen No.	Heating cycle, sec	Upset, in.	Pressure program	Pressure, psi	Shielding gas	Heat treatment	Ultimate tensile strength, 1000 psi	Yield point, 1000 psi	Elongation, %	Bend tests: Pass	Bend tests: Failures, degrees of bend
S-2	10	1/4	C	2,000	None	2 min at 2450° F	76.6	41.8	38.5	8	.....
S-3	10	1/4	C	2,000	None	10 min at 1800° F	75.8	45.1	25.0	4	90-25-160-70
S-4	10	1/4	C	14,000	None	5 min at 1800° F	68.6	50.6	4.5	8	.....
S-5	10	1/4	C	14,000	None	5 min at 1800° F, quenched in cold water	69.0	55.1	10.0	5	90-90-60
S-6	10	1/4	C	14,000	Argon	5 min at 1800° F, quenched in cold water	64.0	47.9	7.5	7	30
S-7	10	3/4	D	14,000	Argon	5 min at 1800° F, quenched in cold water	73.8	48.0	20.0	7	70
S-8	10	1/8	D	14,000	Argon	5 min at 1800° F, quenched in cold water	62.6	48.6	9.0	2	30-30-90-20-30-80
S-10	10	1/16	D	14,000	None	None	Not tested			0	40-0-30-10-10-10-10
S-11	10	1/8	C	14,000	Argon	None	Not tested			0	40-0-60-5-10-60-10-10
S-12	10	1/8	C	2,000	Argon	None	Not tested			4	20-100-70-30
S-13	10	1/8	C	14,000	Argon	None	Not tested			1	90-5-20-30-10-10-10
S-14	10	1/8	C	6,000	Argon	None	Not tested			2	10-20-10-10-20-20

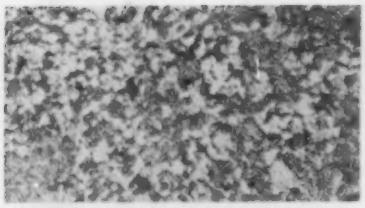


Fig. 11—Fine grained structure at the weld interface of sample CM-67A; × 200 (reduced 50% on reproduction)

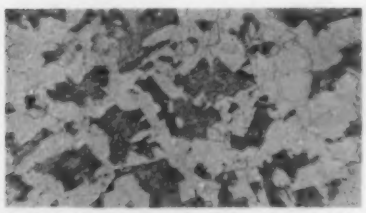


Fig. 12—Structure in the weld zone of sample CM-62B; × 200 (reduced 50% on reproduction)

Fig. 13—Structure at weld interface of sample CM-74. Note absence of ferrite at interface; × 200 (reduced 50% on reproduction)

elevated temperature for varying lengths of time. Tests CM-26 to CM-31 reveal some slight improvement effected by this treatment, but results were still far from satisfactory.

There is evidence, however, in this set of bend test results that suggests more definitely than in the previous series that the welds made on the fast heating cycle are superior to those welded on the slow cycle; i.e., contrast the bend test results of specimens CM-26, 27 and 28 with CM-29, 30 and 31. There was also a difficulty which developed due to the excessive grain growth particularly in those samples held at 2450° F. This occasionally was manifest in bend test failures which occurred in the heat-affected zone adjacent to the weld. Thus high temperature annealing must, of necessity, be limited.

Argon shielding was used in the next series of welds, being applied in the manner described earlier. This series of welds (CM-50 to 59) showed still further improvement over previous work. A subsequent series was tried using argon shielding while varying the amount of upset from $^1/_{16}$ to $^1/_2$ in. These latter welds showed a very definite improvement in the higher upset values. The excellent bend test properties of specimen CM-67A which had a $^1/_8$-in. upset may be compared with specimens CM-63A and CM-64A which had only $^1/_{16}$-in. upset and exhibited rather poor bend test properties. The same trend holds for samples in the series having $^1/_8$- and $^1/_4$-in. upset. There is, however, a serious drawback to using very high upsets in that the excessive weld upset produces profiles that are far from desirable.

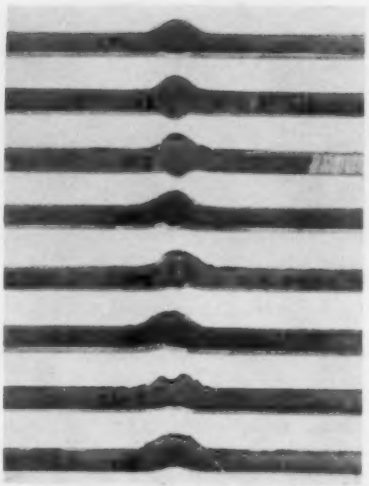


Fig. 14—Weld profiles of samples welded at constant pressure on a 35 sec heating cycle at increasing pressures; outside surfaces uppermost

Sample	Pressure, psi
CM-1	2,000
CM-2	4,000
CM-3	6,000
CM-4	8,000
CM-5	10,000
CM-6	12,000
CM-7	14,000
CM-8	14,000

Metallographic examination of weld CM-67A revealed that the weld plane was completely indiscernible even at a magnification of × 1000—Fig. 11. The severe deformation at the abutting surfaces had squeezed out or dispersed all traces of oxide and a homogeneous fine-grained region extended between the two joined pieces as shown.

A few random tensile tests on some of these samples showed that they exhibited very high ultimate tensile strength and yield point values coupled with very low ductility. A hardness traverse across a few of the welds revealed that the weld zone was considerably harder over a length of $^1/_2$ to $1^1/_2$ in. The difference between the hard zone and the normalized pipe structure amounted to 10–15 points Rockwell B. On the basis of this observation, several experimental heat treatments were carried out on spare blanks from these pipes to try to restore the original ductile properties of the normalized pipe.

Several blanks were heat treated, and tempered at 1250° F. The results of some of these heat treatments are given in Table 1. (The heat-treated coupons are indicated by "*a*".) In every case the coupons which were held at a temperature of 1250° F showed better ductility than the original coupon had before such heat treatment. The ultimate tensile strength and yield point values were lower while percentage elongation was greater by 10% or more. Bend test results were also considerably better in almost every instance.

It appeared, therefore, that some form of post-weld normalizing or tempering was needed to restore the desirable ductile properties to the weld heat-affected zone.

The next series of tests was made using a wide variety of heat treatments including tempering at 1250° F for various lengths of time. Samples Nos. CM-62B to CM-75 show the very much improved results achieved in this series.

Figure 12 is a photomicrograph of the structure at the weld plane of specimen CM-62B which was held at 1250° F for 10 min after welding. The weld interface could not be discerned in this specimen, but the area of the weld contained large grains of ferrite and pearlite.

Figure 13 is a photomicrograph of the weld plane in specimen CM-74 which was quenched immediately after welding and subsequently tempered for 30 min at 1250° F. Here the weld plane is visible due to the orientation of the tempered martensite needles. It should be noted that the argon has effectively prevented oxidation of the interface and thus neither ferrite nor oxide spots are present. Both this specimen and No. CM-62B showed excellent bend test results and mechanical properties.

It is evident that a tempering treatment at 1250° F is essential to producing good welds. To verify this, a final series of welds was made with no other heat treatment than 10 min at 1250° F. Samples CM-77 to CM-82 show the results. It is apparent that good welds can be produced with only this heat treat-

ment if the other conditions of argon shielding and a fast heating rate are used. When the upset values are low, as in sample CM-79, a slight reduction in properties may be expected. The tests made on the 35 sec heating cycle again illustrate the necessity for a confined heated zone for the production of good welds.

Weld Profiles

A further observation on these welds was the variation in weld contour with welding pressure as is evident in Fig. 14. The interior and exterior upsets are quite different and vary with pressure. It is thus evident that by varying the pressure the interior contour may be made almost flat. This was encouraging since previous workers had encountered difficulty in producing welds with acceptable interior profiles.

The fact that most of the upset occurred on the exterior surface suggested that this outer region was probably hotter than the interior and that a thermal gradient existed across the pipe wall. In a few experiments, the thermocouples were placed on both the interior and exterior of the pipe at the weld plane. A two-way switch allowed alternate reading of these temperatures giving a discontinuous measure of temperature at the two surfaces. It was found that in the 35 sec heating cycle there was a difference of 40–50° F at temperatures above 2400° F, while in the 10 sec heating cycle this difference was as much as 150° F.

At lower temperatures, below the Curie temperature, this difference was greater still being as much as 300° F at a temperature of 600° F in a 10 sec heating cycle. Hormann[6] explains this difference in temperature as being due to the better magnetic coupling which occurs at temperatures below the Curie point.

At these temperatures, the heating is very rapid, and because of the skin effect, this occurs principally in the outer surface layers. After the Curie point is exceeded in the outer layers, the inner layers are still heating rapidly due to their magnetic properties, whereas the outer layers are heating more slowly and thermal conduction also helps to even out the temperature gradient. Thus at high temperature, the temperature difference between the outer and inner surfaces is much less than at low temperatures.

A guide to the control of the weld profile thus emerges. If upset occurs at a fairly high temperature as would be the case in samples CM-1, CM-2 or CM-3, then a fairly symmetrical contour of upset metal may be expected and a bulge will occur on both the interior and exterior, the exterior bulge of course always being much larger. If, on the other hand, a high pressure is exerted and upset occurs at a low temperature where the thermal gradient through the pipe wall is considerably greater, then the relatively cold and hence stronger interior surface will upset much less, giving rise to a flatter interior profile such as is exhibited by specimens CM-6 and CM-8. Thus the pressure, in a constant pressure type test, or the time at which upset takes place, in a dual cycle test, are parameters which may be used to good effect in controlling the weld profile.

Finally, there is the variation of weld profile with amount of upset and rate of heating. Figures 15 and 16 show groups of specimens which have had upsets of $^1/_{16}$, $^1/_8$ and $^1/_4$ in. at the heating rates of 10 and 35 sec, respectively. It is interesting to note the differences between the two groups. There is some flaring in the samples welded with the slow heating rate, while in the group where the fast heating rate was used the entire upset is confined to a much smaller length of pipe with a consequently greater amount of metal flow in the immediate vicinity of the joint. Referring back to Table 1 it is now apparent why the welds made with the fast heating rate have superior qualities. The heavy deformation in the vicinity of the weld has obviously broken up any former oxide layer and caused recrystallization in the heavily deformed zone, thus producing a good metal bond. The small exudation of metal at the outer surface was at first thought to indicate slight melting. Metallographic examination did not support this view, and no detrimental properties were ever associated with this type of upset profile.

It is thus shown that acceptable weld contours can be achieved by simple adjustment of the welding process and, further, that pipes welded with these contours, such as CM-77 and CM-78, possess good bend and tensile properties when made under the proper conditions.

Consideration of Inductor Design and Power Requirements

A few experiments were done using compacted iron powder magnetic-shielding rings around the inductor to investigate the effect of concentrating the magnetic field. Two rings were cast using a cold setting resin and −250 mesh hydrogen-reduced iron powder in a ratio of 1 to 10 by weight. These rings were machined to fit closely around the inductor and immediately against it, so as to limit the spread of the magnetic flux—Fig. 17.

Several welds were made using this arrangement with rather interesting results. It was found that a considerably lower power input (about 15% less) was capable of producing the same heating rate in the weld sample. Further, the heated zone was considerably narrower than in the case where the iron powder rings were not used.

These observations suggest that a further modification of inductor design so as to present a narrower inductor face to the workpiece and a more refined device for magnetic shielding around the inductor would result in an even greater reduction in power requirements for welding, as well as provide a more desirable heating configuration in the workpiece. An improvement on the rather elementary arrangement used

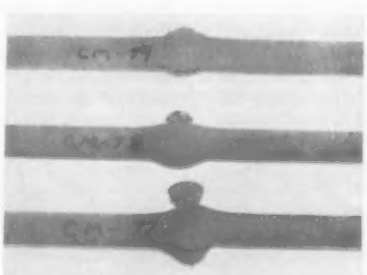


Fig. 15—Weld profiles of samples welded on a 10 sec heating cycle with various upsets; outside surfaces uppermost

Sample	Upset, in.
CM-79	$^1/_{16}$
CM-78	$^1/_8$
CM-77	$^1/_4$

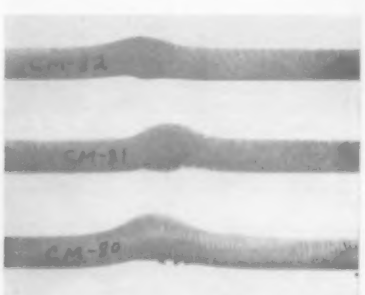


Fig. 16—Weld profiles of samples welded on a 35 sec heating cycle with various upsets; outside surfaces uppermost

Sample	Upset, in.
CM-82	$^1/_{16}$
CM-81	$^1/_8$
CM-80	$^1/_4$

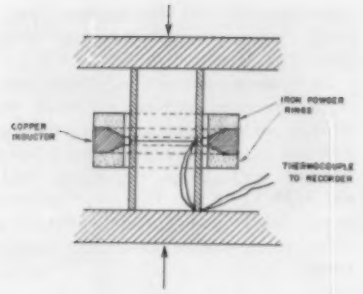


Fig. 17—Experimental arrangement using iron powder magnetic-shielding rings

here would be to surround the inductor with perpendicular lamellae of transformer steel.

Plain Carbon Steel Pipe

Pressure welding of plain carbon steel pipe was considerably easier than welding of Cr-Mo pipe. In these experiments both $1^1/_2$- and $2^1/_2$-in. Schedule 80 pipe were welded. The experimental results are presented in Table 2. The results indicate the wide variation in conditions under which this pipe may be welded. Upsets as little as $^1/_{16}$ in., i.e., 25% of wall thickness, can be quite acceptable if gas shielding is used (see tests C-4, C-7 and C-36), but slightly greater upsets are needed if gas shielding is not used. Slower heating rates may be used with equal success in this thicker-walled pipe without using large upsets or extensive high temperature annealing treatments. It appears that a thick wall makes for easier upsetting without the attendant risk of wall flaring experienced in slowly heated thinner walled samples.

Figure 18 shows some typical profiles from samples of carbon pipe welded with various upsets. All showed excellent mechanical properties.

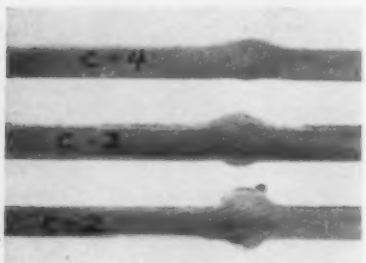


Fig. 18—Samples of carbon pipe welded on a 10 sec cycle with various amounts of upset

Samples	Upset, in.
C-4	$^1/_{16}$
C-3	$^1/_8$
C-2	$^1/_4$

Since this material is not air-hardening, normalizing and tempering treatments are not necessary. Figure 19 is a photomicrograph taken from the weld zone of one of these pipes. There was very marked recrystallization across the weld interface in every instance. The oxide present in the interface, as depicted in Fig. 19, is in the form of fine discrete particles which do not apparently have any detrimental effect on the weld quality.

In summary, plain carbon steel pipes may be joined with or without argon gas shielding with about 50% upset or more and without post weld heat treatment of any kind.

Stainless Steel

A few tests were carried out on 18–8 stainless steel pipe to find out whether the principles applicable to the welding of mild steel and Cr-Mo pipe applied for this material. The results of these experiments are given in Table 3.

There are several important differences between stainless and carbon steel which have a bearing on this welding process. Being non-magnetic, stainless steel has different coupling characteristics when induction heated. This gives rise to a slower rate of heating, resulting in a broader heated zone with greater propensity to flaring during the upsetting operation. Further, since this material does not undergo the austenite/ferrite transformation on heating and cooling, it is more difficult to obtain recrystallization across the weld interface.

The conditions under which welds were made in this material are given in Table 3. It may be noted that the best welds S-2, S-4, S-6 and S-7 were only obtained where high upset values were used coupled with a short post-weld heat treatment at an elevated temperature. It should also be noted that the presence or absence of argon gas shielding does not noticeably affect the results. The disastrous effect of reducing the upset value below $^1/_4$ in. is evident from the properties of sample S-8 and subsequent samples.

Photomicrographs such as Fig. 20 are typical of welds having good bend test properties. The oxide film at the interface is very hard to disperse, even with large upsets and prolonged heat treatment. It is evident, nevertheless, that good welds may be obtained in stainless steel using a fairly substantial upset value and a short post-weld heat treatment.

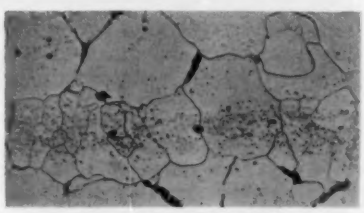


Fig. 19—Weld interface in sample C-22; × 1000 (reduced 50% on reproduction)

Summary

It is apparent from the foregoing results that it is feasible to weld steel piping by induction heating. This welding process can be very rapid, requiring as little as 15 sec. For a carbon steel weld no post-weld heat treatment is required. However, for Cr-Mo and stainless steels a 10 to 15 min post-weld heat treatment is necessary.

The welds produced by the induction welding process have been shown to have properties equal to those attainable by other welding processes. Since this process is machine controlled, a further advantage is obtained in the elimination of the operator variable, which is the source of a great many weld failures. It should be pointed out that the surface must be carefully prepared, but this is not thought to be a major handicap.

It has been demonstrated that one may attain considerable improvement of weld shape in comparison with fusion and flash welding processes. The contour of the weld reinforcement can be readily varied and no difficulty was encountered in attaining a suitable interior surface profile free from any impediment to smooth fluid flow.

Conclusions

The controlling factors in producing acceptable butt welds using the induction heating technique have been shown to be the following:

1. Width of the heated zone: This should be as narrow as possible, a condition that may be obtained by

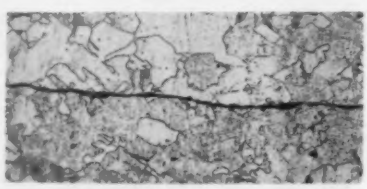


Fig. 20—Photomicrograph of the weld plane in sample S-2; × 200 (reduced about 50% on reproduction)

(*a*) increasing the heating rate (if power capacity is sufficient) and (*b*) by designing the inductor so as to present a narrow inductor face to the workpiece and by placing magnetic inductor shields around the coil.

2. Extent of upset: This should be as large as possible, compatible with attaining an acceptable interior weld profile. Subject to the conditions in Item 1 being optimal, the amount of upset required to obtain a good weld may be reduced. A further reduction in the amount of upset may be allowed in cases where an adequate method of providing inert gas shielding is available.

3. Surface preparation: The surface should be completely free from grease and dirt and should be prepared immediately prior to welding. Care must be taken to assure that the abutting surfaces are flat and make contact across the whole of the surface area. Damage incurred during handling or nonparallel abutting surfaces often results in notches being formed at the weld plane and therefore in poor mechanical properties.

4. Heat treatment: While plain carbon steels and other nonair-hardening varieties may be welded without subsequent heat treatment, it is important, especially in material which does not exhibit a phase change on cooling, to hold the workpiece for a short time at an elevated temperature; 10 min at 1800° F seems to be a reasonable heat treatment, but shorter times may be acceptable at higher temperatures. It should be cautioned that excessive grain growth at high temperatures may result in a loss of properties; therefore, the shorter annealing times are recommended to reduce excessive grain growth and for economy of operation. In steels which are even slightly air-hardening, a post weld heat treatment below the transformation temperature is necessary to restore ductility. Steels which are not normally thought of as air-hardening may turn out to be so under the severe heating and cooling conditions encountered in induction welding.

5. Upsetting pressures: From a metallurgical point of view, the absolute upsetting pressure does not appear to be very important, nor the time of application during the welding cycle. In fact, the welding pressure and its time of application are variables which may be used to control the weld contour provided that the welding surfaces are held in intimate contact from the start of the heating cycle by a small positive pressure. Pressures as low as 2000 psi were sufficient to upset any of the steels used in these experiments at temperatures above 2400° F.

References

1. Kinzel, A. B., "Adams Lecture—Solid Phase Welding," THE WELDING JOURNAL, **23** (12), 1124–1144 (1944).
2. Lytle, A. R., "Oxyacetylene Pressure Welding," *Ibid.*, **23** (12), 1145–1156 (1944).
3. Brown, D. C., and Wilson, J. J., *British Welding Jnl.*, **2**, 160 (1955).
4. British Admiralty Technical Report No. 55/B37.
5. Lytle, A. R., and Morton, W., U. S. Patent Nos. 2,392,824 and 2,354,267.
6. Hormann, E., *Zt. V. D. I.* **96**, 65 (1954).

An Unusual Fracture

BY G. F. MODLEN

In an examination of ductile fracture in steel, notched specimens of the Hounsfield balanced impact type ($^5/_{16}$-in. diam) were bent by placing them lengthwise between the jaws of a vise and then bringing the jaws together. Cracks started to form from the root of the notch and, in commercial mild steel that had been swaged down to size and normalized, the specimen split longitudinally from the notch. The specimen was then sectioned so that the fracture edge might be more easily examined. After polishing, it was possible to make out a crack starting from the edge opposite to the notch, where the metal had been subjected to compression during bending—Fig. 1. The same observation was made upon two mild steels one of which contained very few inclusions and showed little cracking from the base of the notch.

It seemed unlikely that the cracks could arise from the plastic deformation occurring during bending. They were more probably formed by local tensile stresses occurring in the unloading of the specimen. To test this idea, a specimen was made from 1 x $^1/_4$ in. mild steel strip. The specimen was about 6 in. long; a notch was made at its center on its face with a triangular file, and two bolt holes were drilled, each 1 in. from the notch. The specimen was then placed lengthways in a vise and bent by bringing the jaws together. It became possible to place a bolt through the holes provided, and further bending was carried out by tightening a nut on to this bolt. When the specimen had been bent almost double, it was sectioned and examined metallographically, the bolt being in position throughout. The bolt was then removed, and the specimen again examined. It can be seen in Figs. 2 and 3 that the crack has indeed formed on release of the load. It must be admitted that slight traces of a very small crack could be seen before the screw was undone, but this was probably due to some relaxation during preparation for examination. Examination of a $^1/_4$-in. diam round mild steel bar that had been hot-bent to give approximately the same geometry as the Hounsfield specimens showed that cracks started to form on unbending only when the specimen was almost straight. At this point there was some yawning from oxidation pits on the surface. Thus it is the joint action of the internal

(*Continued on page 89-s*)

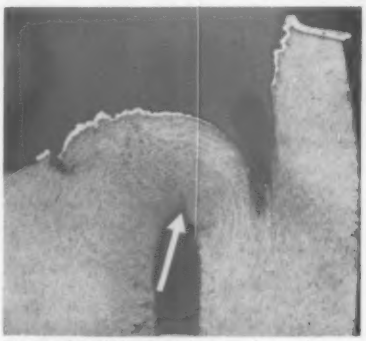


Fig. 1—Crack (arrowed) in region subjected to compression deformation. × 3

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Diffusion Bonding of Zircaloy Plate-Type Fuel Elements

Copper is found to be a reliable medium for diffusion bonding in a helium atmosphere at temperatures up to 1900° F

BY W. LEHRER AND H. SCHWARTZBART

ABSTRACT. A program on the diffusion bonding of plate-type, compartmented ceramic-fuel, Zircaloy nuclear elements has been completed. The fuel element consists essentially of a punched receptacle sheet of Zircaloy-2 bonded to two cover sheets of Zircaloy-2. The function of the receptacle sheet is to form the frames or compartments for the ceramic UO_2 fuel.

The diffusion bonding process as utilized on this program comprised the following main steps:

1. By chemical displacement plating, the punched receptacle sheet was coated with a bonding agent such as copper, iron or nickel.

2. The element was assembled with the ceramic fuel platelets in their compartments, and the three sheets joined around their periphery by tungsten-inert-gas edge arc welding. The ceramic fuel platelets were coated with graphite prior to assembly to inhibit reaction between the UO_2 and the Zircaloy-2 during bonding.

3. The element was heated in helium atmosphere furnace to temperatures from 1600 to 1900° F under positive pressures from 1 to 30 psi and held for times from $^1/_4$ to $3^1/_2$ hr. Bonding was achieved over the entire faying surface areas by formation of low-melting eutectics between the bonding agent and the Zircaloy, and diffusion of the eutectic into the Zircaloy. Under optimum conditions of coating thickness, time and temperature of bonding and heating and cooling rates from the bonding operation, sound bonds were obtained as evidenced by metallographic examination and various mechanical means, including leak tests, chisel tests and internal pressure burst tests. Corrosion behavior of bonded specimens in 680° F water was also ascertained.

Based on the mechanical properties and corrosion resistance of bonded elements and on metallographic observations, copper served best as the diffusion bonding medium. Copper-bonded elements having the best combination of properties had a plated copper thickness of 0.1 mil and were diffusion bonded at 1900° F under 30 psi of helium for periods from $^1/_2$ to 2 hr. The behavior of elements plated with iron was undependable, and voids generally formed in the bond.

The effect of geometry on mechanical properties of the elements is discussed in detail, and the superiority of one geometry over the other clearly shown.

A metallographic study of copper- and iron-plated disks on Zircaloy showed the effects of temperature, time, and heating and cooling rates on the interface reactions. As-plated copper was discontinuous on the Zircaloy, whereas the as-plated iron was a continuous film. With copper, intermediate phases were evident after 15 min at 1450° F and molten material after 15 min at 1550° F. After 15 min at 1650° F, the alloyed copper plate was continuous over the Zircaloy surface.

In the case of iron, a slate-gray layer was observed between the iron plate and the Zircaloy. The layer was postulated to be a barrier layer of oxide, which inhibits diffusion and must be reduced before diffusion can occur. Fifteen minutes at temperatures as high as 1900° F caused no obvious diffusion between the plate and the Zircaloy. The barrier layer showed a visible change after 1 hr at 1750° F and melting of a eutectic phase occurred after 1 hr at 1800° F.

The metallographic study bore out the dependability of copper and the undependability of iron as the diffusion medium.

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., April 25–29, 1960.

Introduction

This paper describes the results of a study of the fabrication of plate-type fuel elements containing compartmented oxide fuel by diffusion bonding. The program was performed under subcontract from the Metallurgy Subdivision of the PWR Project of Westinghouse Bettis Plant, which initially developed this process, as reported elsewhere.[1]

All techniques of fabrication investigated were based on a common principle—that of diffusion bonding. This basic principle involved the introduction of a suitable and compatible second metal or alloy between the two Zircaloy sheets, maintaining intimate contact, and subsequently introducing sufficient heat to cause diffusion and continuous joining of the two sheets. As a corollary, therefore, the program incorporated a study of the preplacement of the diffusion medium—namely, nickel, iron, copper and others. The method adapted for preplacement was an immersion plating from a chemical bath.

This paper will primarily discuss bonding parameters and their effects on mechanical and corrosion behavior; plating parameters have been discussed elsewhere,[2] and the edge arc welding was routine. In addition, a metallographic study of the interface reactions between Zircaloy and copper or iron as the diffusion medium will be presented.

Processing Steps

Principles of the Method

A sandwich consisting of a punched receptacle sheet of Zircaloy between two Zircaloy sheets, completely sealed around the periphery, can, when heated, create a partial vacuum by dissolving the air contained within. This partial vacuum results in a contact being established between the ribs of the receptacle sheet and the inner surface of the cover sheet. A greater intimacy of contact can

be attained by applying an external pressure of an inert gas. The inert gas has the added function of protecting the element from oxidation during the diffusion heating cycle.

Description of Fuel Elements

The fuel elements used in this investigation were specially prepared prototypes of the contemplated production fuel element. The element consists essentially of a punched receptacle sheet of Zircaloy-2 and two cover sheets of Zircaloy-2. The function of the receptacle plate is to form the frame or compartment for the ceramic UO_2 fuel. Both cover sheets and receptacle sheet were $11^1/_4 \times 2^3/_8$ in. The cover sheets used were 0.025-in. thick, whereas the fuel receptacle plate measured 0.080 in. resulting in a total thickness of the element of 0.130 in. after assembly.

Two variations in the receptacle sheet design were used. Type I (EW series) receptacle sheet consisted of fifteen $^1/_4$- × 3-in. fuel compartments with 0.080-in. wide ribs; Type II (AW series) consisted of nine $^1/_2$- × 3-in. fuel compartments and 0.040-in. ribs. These fuel receptacle sheet types are illustrated in Fig. 1. Suitable ceramic UO_2 fuel platelets were provided of dimension to conform with the stamped-out compartments of each receptacle sheet type.

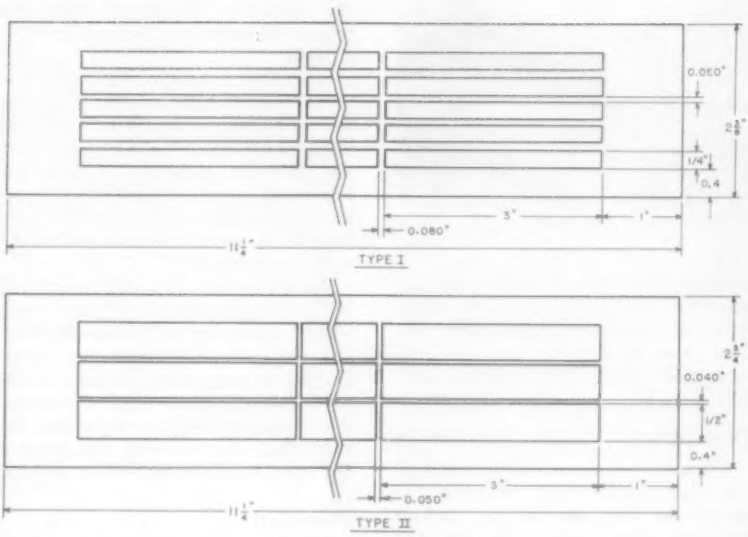

Fig. 1—Design of fuel receptacle sheets, Types I and II

Ceramic UO_2 Fuel Preparation Prior to Assembly

To inhibit the reaction of the UO_2 ceramic fuel with the Zircaloy-2 compartment, a graphite coating was applied, by dipping or spraying, to the surfaces of the UO_2 platelet.

Assembly Procedure

Assembly of the fuel elements was comparatively simple, provided that the cover sheets and fuel receptacle sheet were relatively flat. Some difficulty was experienced when warpage was present, in which case the fuel platelet would slide out of its compartment. Subsequent bonding under these conditions resulted in cracking of the fuel, irregularities of finished surface and loss of contact of rib to cover. With extremely cautious handling, however, these difficulties were largely avoided.

Elements prepared in later experiments contained fuel receptacle sheets that had rib sides not contacting the cover plate scraped free of the plated diffusion medium. During any handling operations of the cover sheets or receptacle sheet, the operator wore clean gloves to maintain grease-free, clean diffusion surfaces.

Final assembly, as the name of the process implies, was accomplished by inert-gas tungsten arc welding completely around the periphery of the assembly and forming a bead joining the cover sheets to the fuel receptacle plate. Jigging for this operation consisted of two copper blocks $11^3/_{16} \times 2^3/_{16} \times 1$ in. held together with 2 C-clamps. The fuel element assembly, when jigged, protruded $^1/_{32}$ in. This protrusion was sufficient to form the weld bead. The copper blocks acted not only as the jigging device but as a large heat sink successfully limiting the penetration depth of the weld and causing rapid freezing of the weld puddle.

Initially, these welds were made manually. An automatic travel-head was incorporated early in the program with excellent results in both weld appearance and performance. The occurrence of faulty welds (leaks) after automatic welding was negligible. The automatic welding was performed at a welding speed of approximately 12 ipm and at a current of 80 amp.

Diffusion Treatment

Assembled and edge-welded fuel elements were diffusion bonded in a 36-in., three-element tube furnace with a specially fabricated vacuum- and/or pressure-tight Inconel-stainless steel retort. Three individual Variacs allowed adjustment of the voltage to the three separate sets of elements so that end effects were minimized to a degree resulting in a uniform "hot zone" exceeding 12 in.

The Inconel-stainless steel retort consisted essentially of a 4-in. ID Inconel tube within the furnace terminated on both ends with a stainless tube surrounded by a water jacket.

Fuel elements emerging from the diffusion-treating furnace were both flat in shape and bright in appearance. This result was due to the development of a stacking technique of the assembled element onto the stainless boat. In contact with the element were two reusable cover sheets acting as a getter for extraneous contaminants and as a protective wall from any possible alloying with the next sheet, molybdenum. Two molybdenum sheets were folded into envelopes to contain the element and the getter sheets with its prime function to inhibit any alloying between the Zircaloy and the stainless boat. It was observed that the greater the area coverage by the molybdenum, the brighter the final fuel element. A plate of $^1/_8$-in. thick steel was used on the top of the stack for purposes of symmetry and promotion of uniform heating of the element on both top and bottom. It had the additional function of uniformly distributing the load created by the iron wires used to bind the stack to the boat.

Figure 2 illustrates the insertion of a completely assembled stack as described above into the retort. After bolting the cover plate, a vacuum was drawn to 0.2 μ while the boat was in the cold zone. The vacuum was then replaced with a

Fig. 2—Insertion of typical diffusion stack into retort

positive pressure of helium and the boat pushed into the hot zone. After a predetermined time, the boat was withdrawn to the cold zone and allowed to cool to 300–400° F before opening the retort.

Evaluations

Each fuel element fabricated during this study was sectioned as shown in Fig. 3. These various sections were subjected to the following tests: leak, chisel, weight-change, integrity and internal-pressure, and metallographic.

Leak Test

The helium leak test was designed primarily for the rapid detection of pinholes in the cover plate and in the edge welds both before and after diffusion bonding. The equipment consists of a steel cylinder with a rapid-opening, pressure-tight cover containing a pressure gage. Close to the pressure cylinder was a tank of ethyl alcohol for immersion of the fuel element and a tank of helium gas for pressurizing the cylinder.

The fuel element was placed in the cylinder, and the top was secured by means of 6 pins located peripherally. The cylinder was charged with 500 psi helium gas and maintained for 5 to 10 min. A valve located at the lower end of the pressure cylinder was rapidly opened to release the pressure, the pins removed from the cover and the fuel element transferred to the tank of ethyl alcohol. The appearance of a small stream of bubbles due to the release of the helium entrapped within immediately located any tiny defect.

This test, however, did not preclude visual examination of the entire specimen. The test indicates nothing if the defect is large, since the internal pressure is lost immediately upon release of the external pressure. This type of large defect, however, was usually detected visually.

In the event of a subvisual leak in either the weld or the cover sheets prior to diffusion bonding, the entire fuel element was found to pillow out upon release of the external pressure. Some caution was required as, on occasion, the pillowing was violent, resulting in the rupture of the face sheet or weld.

Chisel Test

The chisel test consisted of mounting Section C of the fuel element in a vise and forcing a screw driver with hammer blows into cells 11–15. Rupture was found to occur by either the tearing of the cover sheet or the separation of the rib from the cover through the bond. The test did, however, distinguish clearly between those elements in which diffusion was complete and those that had undiffused layers of brittle eutectic in the bond line.

Weight Change in 680° F H_2O

Three solid specimens D, E and F were cut from the ends of the diffusion-bonded fuel element, cleaned with CCl_4 and weighed to the nearest tenth of a milligram. These specimens were then subjected to water at 680° F in an autoclave. After the elapsed time, the specimens were washed free of any sediment and other extraneous matter and reweighed.

The change of weight has been reported herein as a negative or positive per cent change based on an average of the three specimens.

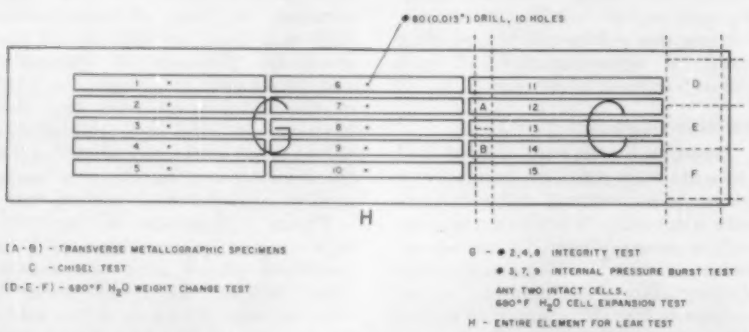

Fig. 3—Sectioning of diffusion-bonded fuel element for examination and testing. Type I

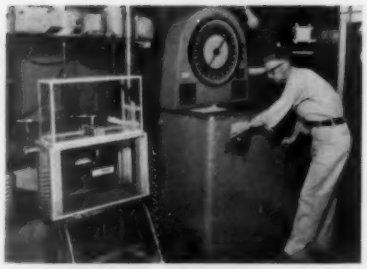

Fig. 4—Set-up for burst, integrity and cell deflection test

Integrity and Internal Pressure Burst Tests

These tests utilized a specially designed fixture consisting essentially of a means of tightening an O-ring fitted tube over a small hole in one cell of a fuel element. The fuel element was supported by a rigid plate with a milled hole of similar shape but larger dimension than the cell directly above. Beneath this plate and projecting up through was a dial gage with a probe contacting the cell being pressurized. A view of the pressure fixture is shown in Fig. 4. The entire fixture required enclosure in a box so that the operator and the surrounding area would not be contaminated with UO_2 dust resulting from the bursting of the cell.

Pressure to the fixture was obtained from a tank of argon gas. A specially designed pressure booster pump was built to increase the tank pressure to 5 times its maximum pressure (10,000 psi) if required. The requirement of a very small capacity based on the total volume of one cell allowed the attainment of these high pressures simply and inexpensively. The booster pump consisted of a simple piston in a cylinder. The pressure booster was used in conjunction with a tensile machine and, in this particular case, rested upon the movable hydraulic platform. The top of the piston was in contact at all times with the fixed crosshead of a tensile machine. With the piston in the up position, the cylinder was pressurized to the maximum pressure attainable from the argon tank. By raising the hydraulic head, the piston compressed the gas in the cylinder and the pressure was easily read off the large dial of the tensile machine.

Prior to testing, all ten cells of the fuel element were defected with a small hole of 0.013 in. diam. For the integrity test, cell Nos. 2, 4 and 8 were subjected to 700 psi of argon. A soap solution was spread over the holes of cells 1, 3, 5, 7, 9

Fig. 5—Type A structure—AW 17 (Cu)—× 100. Diffusion complete with the diffusion medium entirely undetectable in the Zircaloy-2 matrix. The matrix is 100% Widmanstätten structure. (Reduced by 30% upon reproduction)

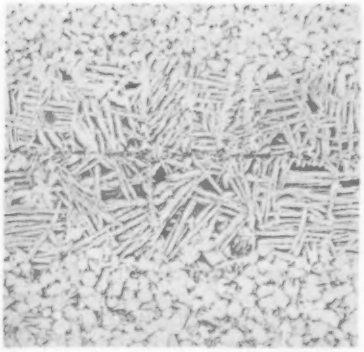

Fig. 6—Type B structure—EW 35 (Cu)—× 100. Diffusion complete in that little or no diffusion medium can be detected in the original interface. The extent of diffusion is delineated through a structure change. (Reduced by 35% upon reproduction)

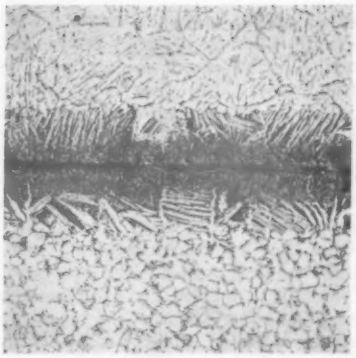

Fig. 7—Type C structure and D structure—AW 21 (Cu)—× 100. A narrow diffusion zone rich in diffusion medium (C). A discrete joint bonded with undiffused filler metal (D). (Reduced by 35% upon reproduction)

(Fig. 3). This test established the integrity of ribs 1-2, 2-3, 3-4, 4-5, 8-3, 8-9, 8-7, 8-13 by closely observing the defects for the appearance of bubbles. It has been pointed out that the integrity of all the edges and ends was established by the 500 psi helium leak test.

Not illustrated in Fig. 3 is the Type II fuel element (AW series). The same principles of integrity testing were used, although with a reduced pressure of 200 psi.

The burst pressure test was performed on the balance of the cells—namely, 3, 7, and 9. Prior to the complete buildup of pressure on each of these cells, integrity was checked in the manner prescribed above, thus accounting for ribs 6-7, 7-12, 9-10, 9-14. Ribs left untested were 5-10, 1-6, 6-11 and 10-15. If all the ribs surrounding the cells maintained integrity, the pressure was built up to the point of fracture of the cell. Simultaneously, the expansion of the cell was measured with the dial indicator. The burst pressure and deflection values presented in the section of results are an average of the three individual cell readings.

Metallography

Sections for metallographic observation were taken from all fuel elements. An arbitrary code was adopted to enable tabulation of the metallographic observations. The code is shown below with representative photomicrographs cited:

A. Figure 5: Diffusion complete with the diffusion medium entirely undetectable in the Zircaloy-2 matrix, which is entirely Widmanstätten in structure.

B. Figure 6: Diffusion complete in that no diffusion medium can be detected in the original faying surface. The extent of the diffusion is visible, however, through (1) a difference in structure from that of the original base metal or (2) a noticeable concentration gradient.

C. Figure 7: A narrow diffusion zone usually rich in the diffusion medium.

D. Figure 7: A discrete joint bonded with undiffused filler metal. This situation was often found in conjunction with a narrow diffusion zone (C).

E. A situation unrelated to the bonding yet accounting for many anomalies in over-all behavior, i.e., poor contact of ribs occurring because of (1) a bent rib causing corner contact with cover plate or (2) oversized fuel, often resulting in poor rib contact while the edges are not affected.

F. Long, narrow line of undiffused alloy.

G. Small, intermittent voids or inclusions occurring in an otherwise excellent bond.

H. Small black specks of unknown nature either intermittent or continuous. These specks appeared in a great many otherwise acceptable bonds.

I. Fig. 8: Large, gross voids—of sufficient size to adversely affect integrity and mechanical strength, and peculiar to Fe-bonded elements.

J. Figure 9: Excessive liquid metal formation occurring either as fillets or large pools within a bond.

K. Visible UO_2-Zr reaction. This can only be a relative evaluation with a distinction, however, made between (1) reaction of UO_2 with an excess of liquid metal and (2) solid reaction. Both conditions are gross and entirely unacceptable.

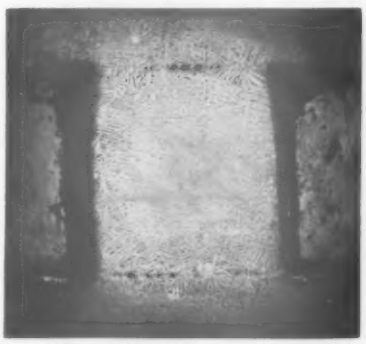

Fig. 8—Type I—EW 45 (Fe)—× 25. Large gross voids peculiar to elements bonded with Fe. (Reduced by 35% upon reproduction)

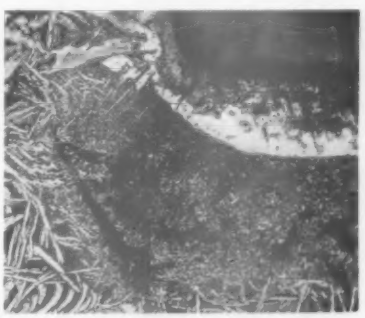

Fig. 9—Type J and K (1)—EW 16 (Cu)—× 100; UO_2-Zr reaction due to the contact of UO_2 with molten eutectic fillet. (Reduced by 50% upon reproduction)

L. No visible bonding anywhere along the faying surface.

Results

A summation of all the elements fabricated with the pertinent fabrication parameters is presented in Tables 1 through 3. Included in

these tables are the results of all examinations and tests performed on the individual elements. The fuel elements are grouped according to the diffusion medium and the type of fuel receptacle sheet.

AW Series—Copper Diffusion Medium

Chisel test results have been graphically represented in Fig. 10. With this representation, some conclusions are immediately apparent. Temperature is seen to influence the results to a greater degree than either time at temperature or plating thickness. Those fuel elements bonded at 1900° F, without exception, performed in a satisfactory manner in the chisel test. At 1800° F, the borderline temperature, the time develops as a factor in that an increasing number of elements fractured satisfactorily (through the cover sheet) as the time was increased from 1/2 to 2 hr. At 2 hr, no failures of bond were in evidence. The time factor was tempered by the plating thickness in that, regardless of the time, any fuel element fabricated at 1800° F having 0.3 mil of copper fractured successfully through the cover plate. At 1700° F, no fuel elements yielded satisfactory results.

The integrity and burst pressure results are illustrated in Fig. 11. These tests tended to reduce the acceptable parameter limits in that elements having satisfactory bonds evidenced by chisel testing failed through lack of integrity. Furthermore, results of burst pressure tests in some cases were contradictory to the results of the chisel test. Cases in point would be elements AW 15, 14 and 4 that are satisfactory in one test but not in another. Nor does one test appear more severe than the other in these cases: for example, AW 15 is borderline in chisel testing and satisfactory in burst pressure whereas the opposite is true for element AW 4. Much of this seeming lack of correlation is due to factors other than diffusion bonding parameters and will be explained in later discussion.

As indicated by the mechanical tests, 1/2- to 2-hr diffusion time at 0.3 mil and 1800° F or over results in a sound bond. For thicknesses as low as 0.1 mil, a diffusion temperature of 1900° F for all times examined resulted in sound bonds, with one exception at 1/2 hr time.

No relationship between deflection or the numerical value of the burst pressure and the time, temperature, thickness parameters was noted.

The evaluations of the change in weight of specimens subjected to 680° F water for one week has yielded some interesting observations. It must be realized, however, that the weight gain, *per se*, is not strictly the measure of the corrosion resistance of the bonded Zircaloy. The weight gain must be considered a net result of two factors: (1) the stringer-type microscopic corrosion resulting in a gain and (2) the formation of loose corrosion product that spalls off. Although the relative effects are unknown, the second has been assumed to be insignificant in that little spalling was noted. The exception to this would be a complete

Table 1—Zircaloy-clad Fuel Elements (Type II Design) Fabricated with Copper as the Diffusion Medium at 30 psi Helium Furnace Pressure

Component no.	Thickness plated, mils	Diffusion temp., °F	Time at temp., hr[a]	Average heating rate 1400 to T° F, °/min	Average cooling rate T to 1400° F, °/min	500 psi helium leak test	Chisel test[b]	Integrity test of cells at 200 psi[c] %	Average burst pressure, psi[b]	Deflection, mils	Corrosion test,[d] avg wt change, %	Metallographic observation[e]
AW-12	0.1	1700	1/2	24.0	174	OK	B	0	..	..	+0.243	C-L
AW-11	0.1	1700	1	19.0	188	OK	B	0	..	..	+0.246	C-E²-L
AW-10	0.1	1700	2	26.6	182	OK	B	0	..	..	+0.178	B-E²-F
AW-9	0.2	1700	1/2	30.6	204	Weld leak	..	..	..	..	..	None
AW-8	0.2	1700	1	28.0	175	OK	B-C	0	..	..	+0.079	C-D-E¹
AW-7	0.2	1700	2	16.0	167	OK	B-C	0	..	..	+0.177	C-D-E²
AW-21	0.3	1700	1/2	17.0	179	OK	B	100	560 (B)	4.2	+0.094	C-D-J
AW-20	0.3	1700	1	18.3	176	OK	B	100	640 (B)	6.0	+0.108	C-D-J
AW-19	0.3	1700	2	19.3	198	OK	B	100	700 (B)	10.5	+0.103	B-F
AW-15	0.1	1800	1/2	25.2	200	OK	7/8C-1/8B	100	1487 (C)	41.3	+0.197	B-F
AW-14	0.1	1800	1	19.2	205	OK	C	50	1430 (C)	34.2		
									480 (B)	..	+0.178	A
AW-13	0.1	1800	2	28.6	200	Pinhole	C	0	..	..	+0.144	A-E¹
AW-6	0.2	1800	1/2	27.0	195	OK	C-B	50	..	..	+0.155	B-D(rib)
AW-5	0.2	1800	1	31.0	182	OK	C-B	100	780	7.0		
									1160 (B)	28.5	+0.113	B-D(rib)-E²
AW-4	0.2	1800	2	33.3	180	OK	C	100	1590 (C)			
									<500 (B)	45.0	+0.082	A-G-E¹-J
AW-22	0.3	1800	1/2	22.0	196	OK	C	100	1350 (C)	44.8	+0.052	B-J
AW-23	0.3	1800	1	21.7	174	OK	C	100	1267 (C)	42.3	+0.098	B-G-J
AW-24	0.3	1800	2	22.0	190	OK	C	100	1310 (C)	41.3	+0.113	A-G-J
AW-18	0.1	1900	1/2	27.8	204	OK	C	100	1470 (C)	47.4	+0.170	A
AW-17	0.1	1900	1	14.0	203	OK	C	100	1433 (C)	46.9	+0.209	A
AW-16	0.1	1900	2	27.0	212	OK	C	100	1467 (C)	39.8	+0.038	A
AW-1	0.2	1900	1/2	22.8	193	OK	C	..	<700 (B)	..	+0.032	A-J-K¹
AW-2	0.2	1900	1	22.8	163	OK	C	75	1170 (C)	27.0	+0.037	A-J
AW-3	0.2	1900	2	30.0	208	OK	C	100	1290 (C)	27.8	+0.039	A-J-K¹
AW-27	0.3	1900	1/2	35.0	186	OK	C	100	1433 (C)	40.8	+0.037	B-J-K¹
AW-26	0.3	1900	1	38.4	198	OK	C	100	1293 (C)	35.8	+0.032	A-G-J-K¹
AW-25	0.3	1900	2	21.2	214	OK	C	100	1570 (C)	32.3	+0.036	A-G-J-K¹

[a] ±10° F of diffusion temperature.
[b] C = cover fracture, B = bond fracture.
[c] Based on 6 cells.
[d] 680° F water, 1 week.
[e] See text for metallographic code.

Table 2—Zircaloy-clad Fuel Elements (Type I Design) Fabricated with Copper as Diffusion Medium

Component no.	Thickness plated, mils	Diffusion temp., °F	Time at temp., hr	Furnace pressure, psi gage	500 psi helium leak test	Chisel test[a]	Integrity test of cells at 700 psi,[b] %	Average burst pressure, psi[a]	Deflection, mils	Corrosion test,[c] avg wt change, %	Metallographic observation[d]	Remarks
EW-4	0.70	1870	2.0	30	Edge leak	C	..	..	..	No test	A-J	
EW-5	2.00	1870	2.0	30	Pinholes over-all	3/4C-1/4B	..	..	..	No test	A-G-J	Copper diffused through to surface
EW-6	0.10	1870	2.0	30	OK	B	..	..	..	No test	L	
EW-13	0.3	1800–1850	3.5	30	OK	C	100	3200 (C)	8.0	..	A-J-K[1]	
EW-16	0.39	1800–1850	2.0	30	Pinhole	C	100	3327 (C)	5.8	..	A-G-J-K[1]	
EW-17	0.30	>1850	3.0	30	Pinholes	C	100	3280 (C)	5.0	..	A-F	
EW-18	0.20	1800–1850	3.0	30	OK	C	100	3083 (C)	5.1	..	A-J-K[1]	
EW-19	0.354	1800–1850	3.0	30	Pinhole	C	100	3553 (C)	3.8	..	None	
EW-20	0.20	1750–1800	2.0	30	OK	C	100	3673 (C)	6.5	..	B-H-K[2]	
EW-21	0.25	1750–1800	2.0	30	OK	C	100	3300 (C)	5.1	..	A-H-J-K[1, 2]	
EW-23	0.26	1650–1700	2.0	30	OK	C	100	3233 (C)	9.5	..	B-H-J	
EW-24	0.26	1600	2.0	30	OK	B	100	<2000 (B)	..	..	C-D	
EW-31[e]	0.14	1650	2.5	30	OK	B	100	3890 (C)	6.9	Bulk of load eroded out	B-H	
EW-33	0.11	1650	2.0	16	OK	B	100	1500 (B)	..	+0.108	B-F	
EW-34	0.10	1650	2.0	30	OK	B	100	2100 (B)	..	+0.136	B-F	
EW-35	0.18	1650	2.0	30	OK	C	100	3700 (C)	8.9	+0.095	B-H	
EW-36	0.18	1650–1700	2.0	15	OK	3/4C-1/4B	100	3850 (C)	9.1	+0.035	B-H-G	
EW-37	0.19	~1650	2.0	30	OK	..	..	..	..	..	..	
EW-38	0.19	~1650	2.0	30	OK	..	..	..	..	..	..	
EW-47	0.19	1650	3.0	7	OK	B	100	3087 (C)	9.1	+0.018	B-G-H	
EW-48	0.19	1600–1650	2.0	~1	OK	B	100	3060 (C)	5.3	+0.019	B-G-H	
EW-53	0.21	1790 ± 10	2.0	30	OK	C	100	3560 (C)	10.5	+0.024	A-G-H-K[2]-E[3]	Fuel oversized; no neolube used
EW-54	0.21	1790 ± 12	2.0	15	OK	1/2C-1/2B	100	3810 (C)	7.6	+0.022	B-I-K[2]-E[2]	Fuel oversized; no neolube used
EW-55	0.20	1795 ± 5	2.0	7	OK	1/4C-3/4B	50	3410 (C)	13.6	+0.042	A-G-H-K[2]-E[3]	Fuel greatly oversized; no neolube
EW-56	0.20	1800 ± 0	2.0	~1	OK	1/4C-3/4B	100	3553 (C)	7.1	+0.028	A-F-K[2]-E[3]	Fuel greatly oversized; no neolube
EW-59	0.14	1800 ± 10	1/4	30	OK	1/2C-1/2B	100	3320 (C) 3800 (B)	8.0 ..	+0.139	C	
EW-60	0.14	1745 ± 5	1/4	30	OK	B	0	..	..	+0.363	C-F-E[2]	Fuel greatly oversized
EW-61	0.10	1850 ± 0	1/4	30	OK	B	0	..	..	8+0.072	C-I-E[3]	Fuel oversized
EW-62	0.10	1847 ± 2	1/2	30	OK	3/4C-1/4B	0	..	..	+0.086	A-G-H	
EW-63	0.14	1745 ± 5	1/2	30	OK	C	100	2675 (C)	5.7	+0.237	C-H-E[2]	Fuel oversized; imperfect contact
EW-64	0.14	1750	1/2	30	OK	C	100	3700 (C) 2200 (B)	8.5 ..	+0.110	C-F	
EW-65	0.21	1845 ± 5	1/4	30	OK	C	100	2987 (C)	4.9	+0.0266	B-G-F	
EW-66	0.21	1845 ± 5	1/2	30	OK	C	100	3100 (C)	7.3	+0.0216	B-H	
EW-67	0.10	1895 ± 5	1/4	30	OK	1/2C-1/2B	0	2700 (B)	..	+0.0862	A-F	

[a] C = cover fracture, B = bond fracture.
[b] Based on 10 cells tested.
[c] 680° F water, 1 week.
[d] See text for metallographic code.
[e] All specimens from EW-31 had plated metal removed from noncontacting surfaces prior to assembly.

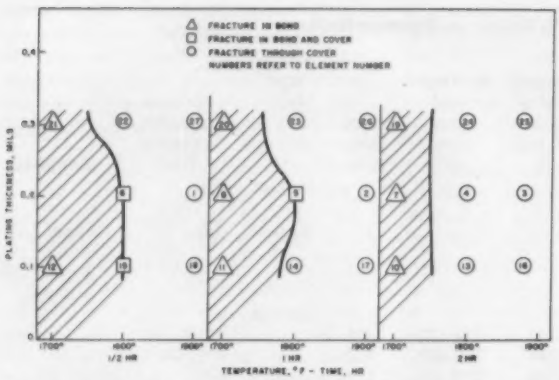
FRACTURE IN BOND
FRACTURE IN BOND AND COVER
FRACTURE THROUGH COVER
NUMBERS REFER TO ELEMENT NUMBER
PLATING THICKNESS, MILS
TEMPERATURE, °F - TIME, HR

Fig. 10—Graphic representation of fuel element quality as a function of fabrication time, temperature and copper plating thickness based on chisel tests. Type II design

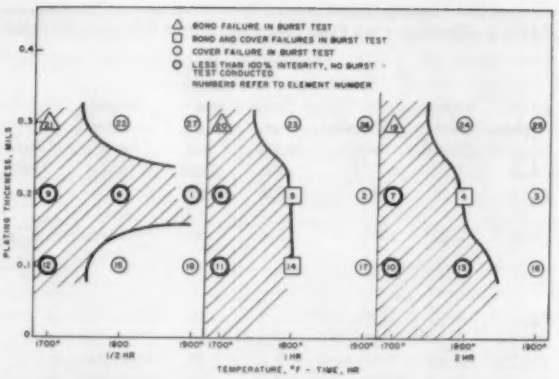
BOND FAILURE IN BURST TEST
BOND AND COVER FAILURES IN BURST TEST
COVER FAILURE IN BURST TEST
LESS THAN 100% INTEGRITY, NO BURST TEST CONDUCTED
NUMBERS REFER TO ELEMENT NUMBER
PLATING THICKNESS, MILS
TEMPERATURE, °F - TIME, HR

Fig. 11—Graphic representation of fuel element quality as a function of fabrication time, temperature and copper plating thickness based on integrity and burst pressure tests. Type II design

erosion of the bond line resulting in the sample falling apart. Even under these conditions, the net weight change was positive.

A bar graph is presented in Fig. 12 where the three parameters are plotted vs. the average weight gain. Immediately apparent in this graph is the general trend to lower percent weight gain with increasing temperature for all times and thicknesses. In general, increasing plating thickness also results in decreasing weight gain, particularly at 1700° F. It is interesting to note that a temperature of 1900° F results in a nearly constant weight gain for all specimens with 0.2 and 0.3 mil of copper plate regardless of whether the time is $^1/_2$, 1 or 2 hr.

Examination of metallographic structures in an attempt to reasonably explain the above relationships leads to the conclusion that the low weight gain is primarily related to total diffusion of the diffusion medium and a continuous Widmanstätten type structure (structure Type A). Due to the constancy of weight gain at 1900° F for a range of thicknesses of copper plate representing 0.11 w/o to 0.32 w/o copper homogeneously dispersed through the Zircaloy matrix, it can be concluded that small copper additions to Zircaloy are innocuous. The general decrease in over-all weight gain with increasing copper plating thickness for temperatures lower than 1900° F (1800 and 1900° F) is yet inexplicable.

In the last analysis, the metallographic appearance of the bond and associated matrix structure is the deciding factor in the choice of the optimum combination of parameters. Due to the association of the A type structure with low weight gain, many combinations of time, temperature and thickness can be eliminated from further consideration by merely a metallographic evaluation of the bond. The A structure occurs in those elements bonded at 1800 F, for 1 and 2 hr with 0.1 mil copper and 2 hr for those elements with 0.2 and 0.3 mil copper. The mechanical tests, however, show most of these parameter combinations to be unreliable, due not to structure but primarily to poor rib contact.

Table 3—Zircaloy-clad Fuel Elements (Type I Design) Fabricated with Iron as Diffusion Medium at 30 psig Furnace Pressure

Component no.	Thickness plated, mils	Diffusion temp., °F	Time at temp., hr	500 psi helium leak test	Chisel test[a]	Integrity test of cells at 700 psi,[b] %	Average burst pressure, psi[a]	Deflection, mils	Corrosion test,[c] avg wt change, %	Metallographic observation[d]
EW-25	0.25	1800	2.0	OK	C	100	3380 (C)	9.4	..	A-G-K[3]
EW-26	0.25	1650	3.0	OK	B	100	2520 (B)	..	..	B-I-F
EW-27	0.15	1700	3.0	OK	$^1/_4$C-$^3/_4$B	..	<700 (B)	..	+0.38	B-I-F
EW-28	0.15	1700	2.0	OK	C	100	3230 (C)	8.0	+0.24	B-H-I-F
EW-29	0.2	1700	3.0	OK	B	..	<700 (B)	..	+0.20	B-L
EW-30	0.2	1750	2.0	OK	B	100	3868 (C)	6.3	Fell apart	B-H-G
EW-39[e]	0.18	1700	0.5	OK	B	..	<700 (B)	..	+0.146	B-I-F
EW-40	0.18	1700	1.0	OK	B	..	<700 (B)	..	+0.193	B-I-F
EW-41	0.08	1800	1.0	OK	B	..	<700 (B)	..	+0.267	B-I-F
EW-42	0.08	>1800	1.0	OK	B	..	<700 (B)	..	+0.103	B-F-I
EW-43	0.22	1750–1800	1.0	OK	C	100	3010 (C)	5.0	+0.056	B-H
EW-44	0.22	1882 ± 5	1.0	OK	C	100	3330 (C)	6.9	+0.025	A-H
EW-45	0.30	1650–1700	1.0	OK	C	100	3142 (C)	7.0	+0.028	B-H-I-K[3]
EW-46	0.30	1882 ± 5	1.0	OK	$^1/_2$C-$^1/_2$B	100	3227 (C)	7.3	+0.023	A-H-I-K[3]

[a] C = cover fracture, B = bond fracture.
[b] Based on 10 cells tested.
[c] 680° F water, 1 week.
[d] See text for metallographic code.
[e] All specimens from EW-39 had plated metal removed from noncontacting surface prior to assembly.

Excellent mechanical properties were noted for the element fabricated at 1800° F for 2 hr containing 0.3 mils copper, but metallographic examination revealed excess fillets formed. A temperature of 1800° F, therefore, appears to be unsatisfactory.

All elements fabricated at 1900° F with one exception, (0.3 mil—$^1/_2$ hr) exhibit an A structure with the resultant excellent mechanical properties and corrosion resistance. Apparently, 1900° F is a sufficiently high temperature to overcome the effect of poor contact due to bent ribs. Thicknesses greater than 0.1 mil, however, exhibited excessive filleting at 1900° F. This filleting often resulted in a reaction between the UO_2 and Zr despite the sprayed graphite coating on the UO_2. The coating did, however, arrest and apparently eliminate the solid-state reaction of the UO_2 with the Zr.

It may be concluded, therefore, that the Type II fuel receptacle sheet may be successfully bonded, taking all that is known at present into consideration, at 1900° F with an 0.1 mil copper plate. At this thickness and temperature, time at diffusion temperature between $^1/_2$ and 2 hr has no effect.

Table 1 lists the heating and cooling rates through a range of 1400° F, to diffusion temperature. This range was selected as encompassing the α-β transformation of Zircaloy-2. Although very little variation was allowed, the varying rates recorded had little or no effect on the end result.

EW Series—Copper Diffusion Medium

Table 2 lists the fuel elements fabricated with the Type I fuel receptacle sheet and results obtained from the tests of these elements. The same methods of representing the data obtained upon testing have been utilized in the evaluation of this series as used with the AW series. Figures 13 and 14 are schematic representations of the chisel and the integrity and burst tests, respectively. Figure 15 is a bar graph illustrating the percent weight gain of samples cut from the fuel elements and subjected to 680° F H_2O for 1 week. The weight gain has been plotted against plating thickness, temperature and time with a fourth variable of furnace pressure. The effect of furnace pressure during diffusion on mechanical properties has been graphically represented in Fig. 16.

Reference to the graphic representations of the chisel, integrity, and burst pressure results yields somewhat different conclusions than those obtained from the mechanical tests performed on the AW series. From these results, time has been established as a factor, in that $^1/_4$ hr appears to be too close to minimal to be considered safe in production. Only at >0.2 mils and >1850° F can this short a time yield satisfactory mechanical properties. On the whole, the burst pressure test and the chisel test gave congruous results. It is immediately apparent, however, that satisfactory mechanical properties have been obtained at lower temperatures (1650° F) with the EW series than with the AW series (Type I vs. Type II fuel receptacle sheet). Furthermore, the burst pressures are nearly 3 times greater than those obtained from the AW series, and the cell deflections are nearly 3 times less. (Compare pertinent columns in Tables 1 and 2.)

Further wide differences in the behavior of AW series and EW series are noted when comparing metallographic appearance with the mechanical properties. Whereas few, if any, incompletely diffused structures or matrices exhibiting both equiaxed and Widmanstätten microstructures (Type B) yielded satisfactory mechanical properties in the AW series, many such structures exhibited excellent mechanical

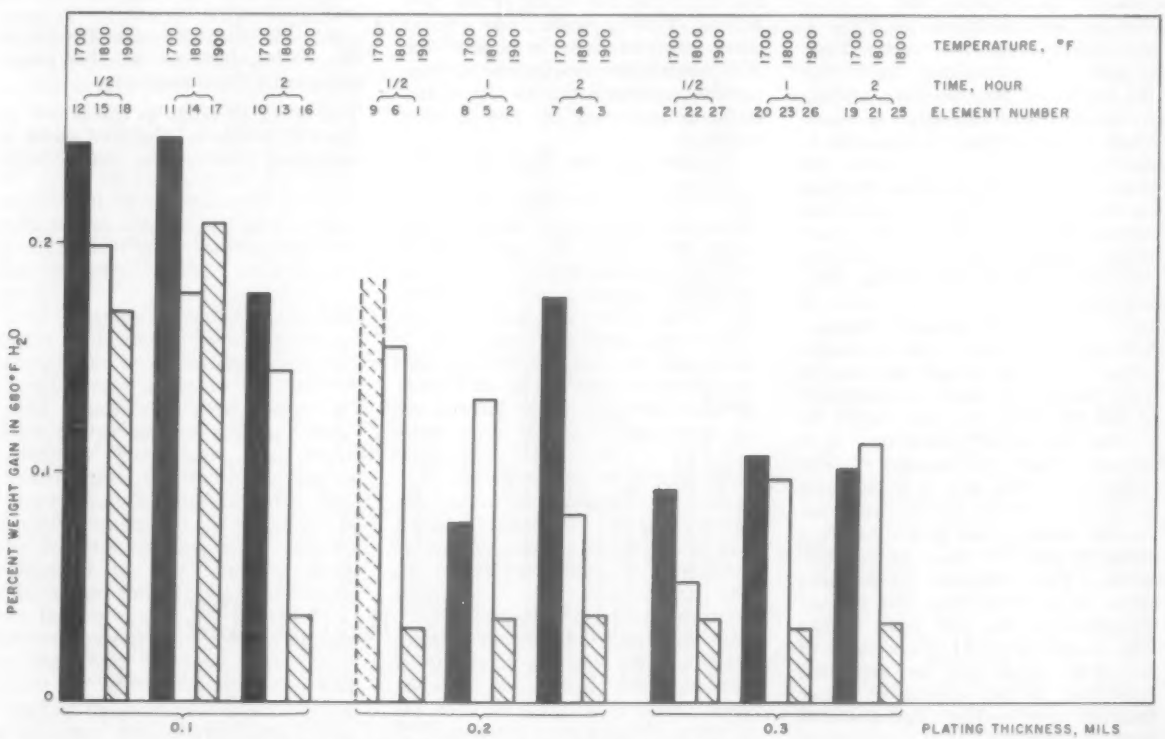

Fig. 12—Bar graph of percent weight gain in 680° F H_2O as a function of fabrication time, temperature and copper plating thickness. Type II design

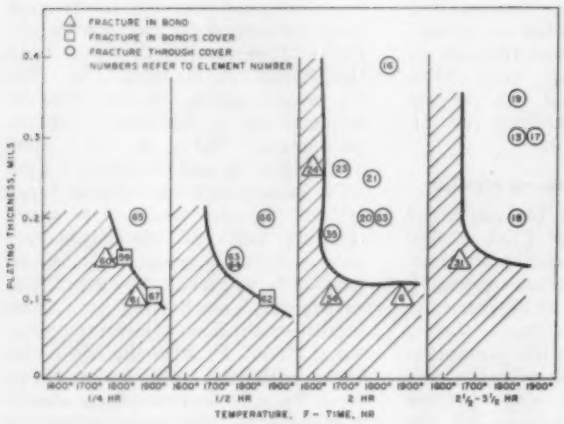

Fig. 13—Graphic representation of fuel element quality as function of fabrication time, temperature and copper plating thickness based on chisel tests. Type I design

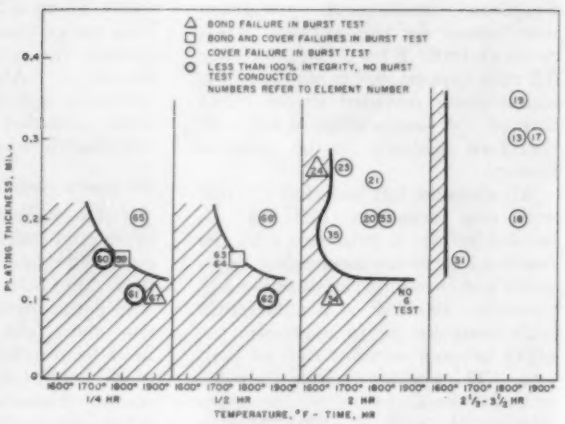
BOND FAILURE IN BURST TEST
BOND AND COVER FAILURES IN BURST TEST
COVER FAILURE IN BURST TEST
LESS THAN 100% INTEGRITY, NO BURST TEST CONDUCTED
NUMBERS REFER TO ELEMENT NUMBER
PLATING THICKNESS, MILS
NO G TEST
TEMPERATURE, °F - TIME, HR
1/4 HR
1/2 HR
2 HR
2½-3½ HR

Fig. 14—Graphic representation of fuel element quality as a function of fabrication time, temperature and copper plating thickness based on integrity and burst pressure tests. Type I design

properties in the EW series. Furthermore, voids in the bond (to a certain magnitude) have little effect on the mechanical properties in the EW's whereas the AW's are extremely sensitive to such faults.

The above variations in results between the AW and EW series fuel elements are easily rationalized through consideration of the dimensional differences between the Type I (EW) and Type II (AW) fuel receptacle sheets. Type II elements have twice the surface area per compartment as Type I and one-half the rib width—Figs. 1 and 17. Consider now the two modes of failure—through the cover sheet and through the bond. When a compartment is pressurized, the cover sheet is subjected to tensile and bending stresses, whereas the bond is subjected to shear and tearing stresses. The cover sheet of the bonded AW element, having twice the surface area of the EW, has twice the force acting upon it for a comparable pressure reading. Assuming the cover sheet would fail at the same tensile stresses in both cases, the pressure required to fail the AW element should be $^1/_2$ that for the EW element. It is actually found to require $^1/_3$ the pressure to fail the AW element cover, a fact which can be explained on the basis of the larger bending stress in the AW than in the EW series. The difference in bending stress is evident from the greater deflection in the AW than in the EW elements. The cover sheet of the AW series can be expected, therefore, to fail always at lower internal unit loading than the EW series cover sheet.

The same reasoning is applicable to the failure of the bond due to the tearing stress. When considering this stress component, the rib width plays no role; the tearing stress is a function of the deflection only. Rib width, however, does play a role in the ability of the bond to withstand the shear load component of the internal stress. For a given shear load, the wider rib has a lower unit shear stress than a narrow rib and can, therefore, tolerate a bond of poorer quality. Such is the case with the EW series that has twice the rib width of the AW series. Furthermore, the shear stress imposed upon the bond of the EW series is necessarily less at comparable pressures due to the added stiffness imparted by the greater width.

To sum up, the Type II (AW) elements exhibit lower burst pressures than the Type I (EW) elements because:

1. To obtain a given tensile stress in the cover sheet requires half as much pressure.
2. Bending stresses in the cover sheet are greater.
3. The greater deflection causes greater tearing stress at the intersection of rib and cover.
4. The shear strength is lower because the rib is half as wide, giving half the bonded area.
5. The shear stress is greater in the bond because of the lesser stiffness of the narrow rib.

The effect of voids in the bonds of the EW series vs. the AW series is explained also on the basis of the

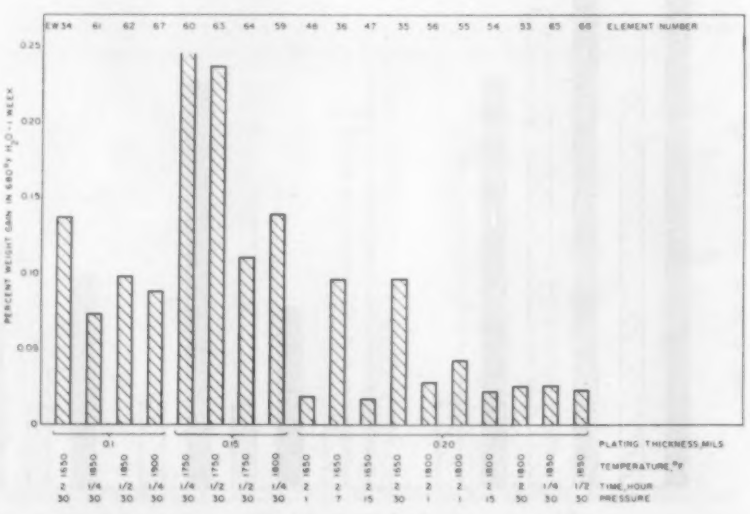

Fig. 15—Bar graph of percent weight gain in 680° F H_2O, 1 week, as a function of fabrication time, temperature, copper plating thickness, and furnace pressure. Type I design

rib width. Metallographically, a given set of parameters produces the same structures and the same defects in both types of elements. It has been mentioned that voids, for example, have less effect on the mechanical properties and the integrity when occurring in the EW series than they do in the AW series. Apparently, the same size void can be continuous in the narrow rib bond whereas this same void occupies only a portion of the rib area if the rib is wider. Hence, a loss of integrity in the case of the narrower rib and greater apparent loss in mechanical strength.

One obvious conclusion to be drawn from the above discussions is the mechanical superiority of the Type I fuel receptacle sheet over the Type II sheet and the greater latitude it would inherently give to the fabricator in the production of satisfactory, high-integrity fuel elements. The occurrence of bent ribs, for example, was frequent in the AW series which yielded point contact on bonding and loss of integrity. This condition did not occur in the EW series.

It has been shown that the mechanical properties of the diffusion bond are greatly influenced by the geometry of the receptacle sheet. Corrosion resistance and the microstructure are not. Reference to Fig. 15 indicates that the same general conclusion may be drawn for the EW series as was drawn from the AW series. A plating thickness of 0.2 mils copper and a diffusion temperature in excess of 1800° F usually resulted in the minimum weight gain. The microstructures of these elements were the same as those observed in the study of the AW series, that of complete diffusion and a continuous Widmanstätten pattern (A-Type microstructure).

As mentioned earlier, this EW series of elements included an investigation to determine the minimum furnace pressure that would yield consistently good contact of bonding surfaces at diffusion temperature. The chisel and burst pressure tests for this investigation were entirely incongruous (Fig. 16). Vividly illustrated in Fig. 16 is the severity of the chisel test as compared to the burst pressure test—again directly attributable to the fuel receptacle sheet geometry. Differing from the $^1/_2$-in. wide cell of the Type II sheet, the $^1/_4$-in. wide cell of the Type I sheet is much stiffer and unyielding during a hammer and chisel blow. The shock stress, therefore, is translated essentially undiminished to the bond. Be that as it may, 30 psi was required to fabricate elements to withstand the chisel test satisfactorily. The metallographic appearance of the bonds, however, showed little effect of pressure.

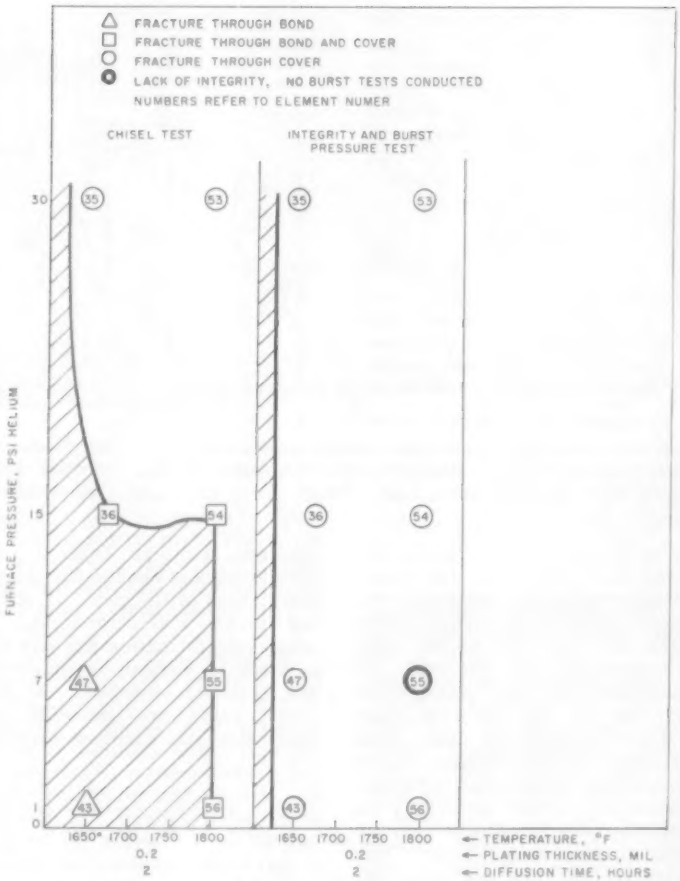

Fig. 16—Graphic representation of fuel element quality as a function of fabrication temperature vs. furnace pressure based on chisel, integrity and burst pressure tests. Type I design

Metallographic examination specifically for evidence of the solid state UO_2-Zr reaction revealed that the pressure was a negligible factor within the limits of pressures investigated, 1 to 30 psi.

It is concluded, therefore, that the higher pressure is to be desired in that the effect of inadvertent fabrication errors, as oversized fuel or cracked fuel chips, is more likely minimized.

In summary, the conclusions regarding optimum parameters must be the same as those concluded for the AW series, e.g., 1900° F, and 0.1 mil thickness of copper. Few EW elements were actually made at these parameters, and those that were made had too short a diffusion

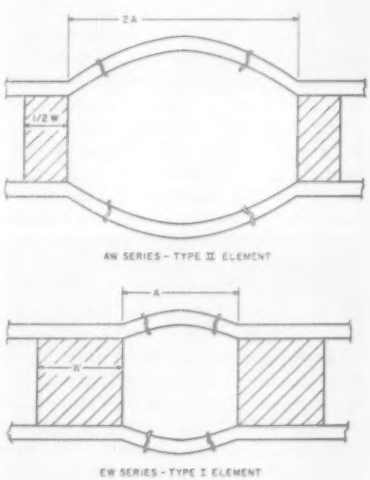

Fig. 17—Effect of geometry on bursting properties of Type I and Type II compartments pressurized to the same pressure

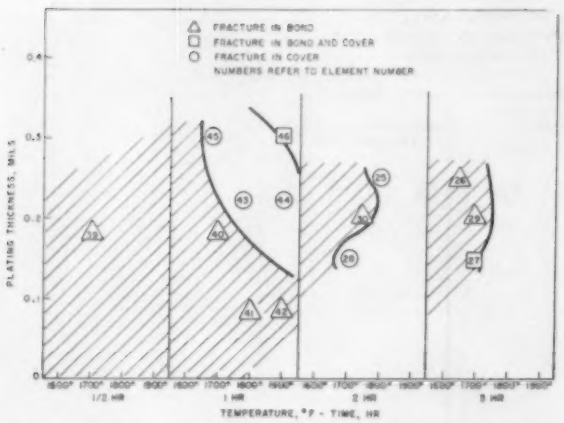
FRACTURE IN BOND
FRACTURE IN BOND AND COVER
FRACTURE IN COVER
NUMBERS REFER TO ELEMENT NUMBER
PLATING THICKNESS, MILS
TEMPERATURE, °F - TIME, HR

Fig. 18—Graphic representation of fuel element quality as a function of fabrication time, temperature and iron plating thickness based on chisel tests. Type I design

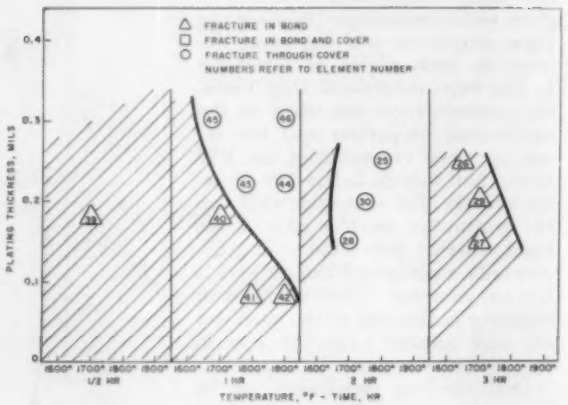
FRACTURE IN BOND
FRACTURE IN BOND AND COVER
FRACTURE THROUGH COVER
NUMBERS REFER TO ELEMENT NUMBER
PLATING THICKNESS, MILS
TEMPERATURE, °F - TIME, HR

Fig. 19—Graphic representation of fuel element quality as a function of fabrication time, temperature and iron plating thickness based on burst pressure tests. Type I design

time to be conclusive. It may be pointed out that at this small thickness, 30 psi pressure may be marginal in that the contact force on the rib is only one-half that which is on the AW series rib. It is suggested that the pressure be raised to 60 psi when bonding the Type I receptacle plate, thus equalizing the parameters. It is believed that, under the above circumstances, the EW series may be adequately bonded if the time at temperature exceeds $^1/_2$ hr. The maximum time has not been determined but apparently will depend on the quality of the UO_2-graphite coating, which in the case of the AW series was adequate up to the maximum time investigated, 2 hr.

EW Series—Iron Diffusion Medium

The description of fabrication parameters and results using iron as the plated diffusion medium are tabulated in Table 3. Although a limited number of elements were fabricated as compared to elements using copper, sufficient data were obtained to warrant graphic representations. Figures 18, 19, and 20 show the results of the chisel tests, burst tests and per cent weight gain in 680° F H_2O respectively. Comparison of Figs. 18 and 19 again illustrates the added severity of the chisel test over that of the burst pressure test.

Elements bonded for longer than 2 hr in the same temperature range at comparable plating thickness appear to lose mechanical strength, whereas no such phenomenon was noted when diffusing with copper. Again, however, the deciding factor lay in the metallographic examination. Few, if any, bonds made with iron as a diffusion medium appear voidless. Note in Table 3, under metallographic results, the constant appearance of the code "I" signifying gross void formation. This gross void formation appears to be peculiar to elements using iron as the diffusion medium. Although these voids are generally gross their size and numbers appear to be definitely time-dependent—the longer the time, the more serious the condition.

Considering the effect of temperature on weight gain (Fig. 20), 1900° F produces the elements with the least weight gain. These elements were diffusion-treated for 1 hr with 0.2 and 0.3 mil of plated

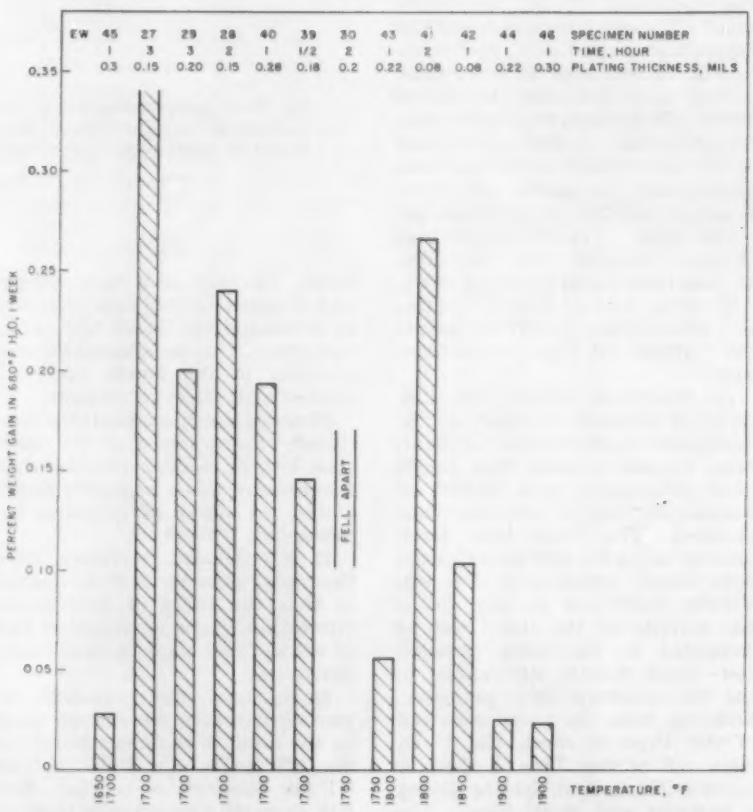

Fig. 20—Bar graph of percent weight gain in 680° F H_2O, 1 week, as a function of fabrication time, temperature and iron plating thickness. Type I design

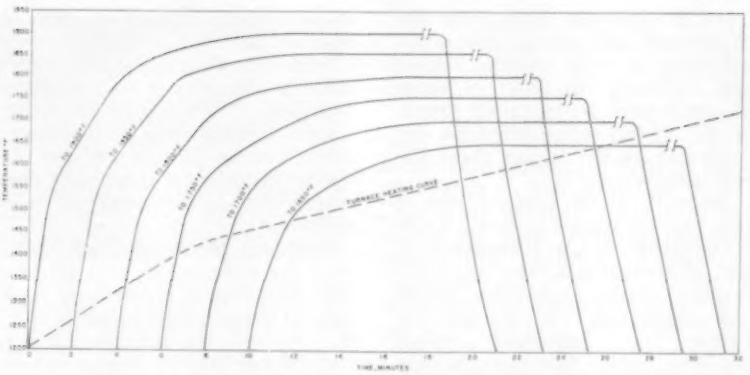

Fig. 21—High and low heating rates and cooling rates for diffusion specimens

iron. Again, this small weight gain was associated with complete diffusion and Widmanstätten structure (A-type). The element fabricated with 0.3 mil Fe, however, showed an excessive void formation resulting in poor mechanical properties (element EW 46). This leads to the belief that the void formation is not only directly proportional to the time but also to the quantity of iron present.

In conclusion, an element fabricated at 1900° F for 1 hr and 0.2 mil Fe has exhibited all the desirable properties. Despite this, the use of iron as a diffusion medium is far less desirable than the use of copper. The dependability and capacity to produce sound, voidless bonds leave much to be desired. This is due primarily to the added influence of thickness and time on void formation.

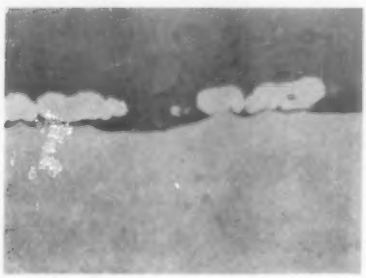

Fig. 22—As-immersion-plated copper on Zircaloy-2 (Courtesy WAPD G-Bldg. Metallographic Lab.)—× 500. (Reduced by 50% upon reproduction)

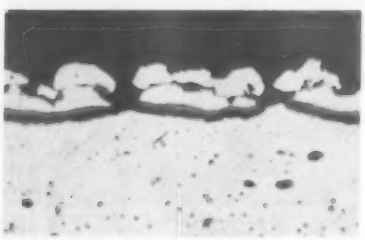

Fig. 23—Diffusion of Zircaloy and copper plate after 15 min at 1450° F. High heating rate—× 1000. (Reduced by 50% upon reproduction)

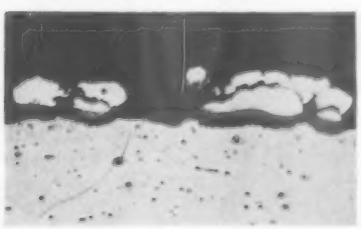

Fig. 24—Diffusion of Zircaloy and copper plate after 15 min at 1500° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

Metallographic Study of the Interface Reactions Between Zircaloy and Copper or Iron as the Diffusion Medium

A metallographic study was carried out to study the interface reactions between Zircaloy and copper or iron, and the dependence of these reactions on temperature, time, heating rate and cooling rate.

Procedure

Zircaloy strips of 0.078-in. thick fuel receptacle material and 0.025-in. thick cover plate material were immersion-plated with copper or iron in the form of a disk. The disks were nominally 0.2 mil thick and $^3/_8$ in. in diam.

The specimens, encapsulated in Vycor bulbs containing argon, were heat treated at various temperatures for various times. Two different heating rates were utilized; fast heating was accomplished by inserting the bulb into the furnace at the predetermined heat treating temperature, and slow heating by inserting the bulb into the furnace at 1000° F and bringing the furnace and specimen to the desired heat treating temperature. Sample heating curves to various temperatures are illustrated in Fig. 21. Included in this illustration is the furnace heating curve that is unchanged regardless of what temperature was ultimately attained. Two different cooling rates were used in the thermal cycle: a fast air cool (Fig. 21) and a furnace cool of approximately 15°/min.

After heat treatment the specimens were visually examined for evidence of flow, sectioned, and examined metallographically for the degree and mode of diffusion and for evidence of molten phases.

Diffusion of Zircaloy and Copper

The immersion plate of copper on Zircaloy is porous and discontinuous, as illustrated in Fig. 22. This very discontinuity, however,

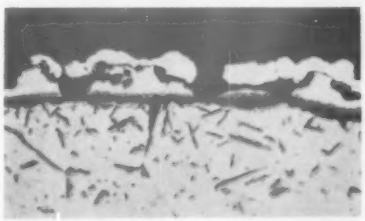

Fig. 25—Diffusion of Zircaloy and copper plate after 15 min at 1550° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

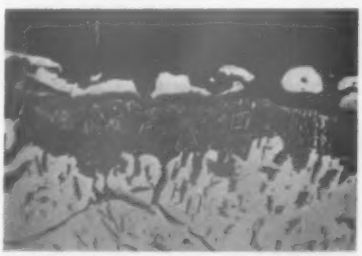

Fig. 26—Diffusion of Zircaloy and copper plate after 15 min at 1600° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

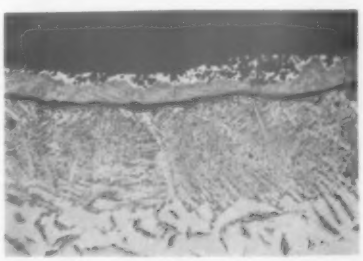

Fig. 27—Diffusion of Zircaloy and copper plate after 15 min at 1650° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

simplified the determination of the temperature at which a molten phase appears, as is illustrated in the series of micrographs following.

Figures 23 to 30 illustrate the degrees of diffusion occurring between the copper and Zircaloy after 15 min at increasing temperatures. The specimens illustrated were heated rapidly and cooled rapidly (Fig. 21).

At 1450° F after 15 min, at least 5 solid phases of the copper-zirconium system are clearly evident due to the diffusion of the Zircaloy into the copper. These phases are difficult to discern in the black-and-white illustrations utilized in this paper but are very clear under the microscope, especially because of the difference in color between copper and Zircaloy. At 1500° F, those phases present have visibly broadened. At this temperature the discontinuity of the copper plate was still maintained.

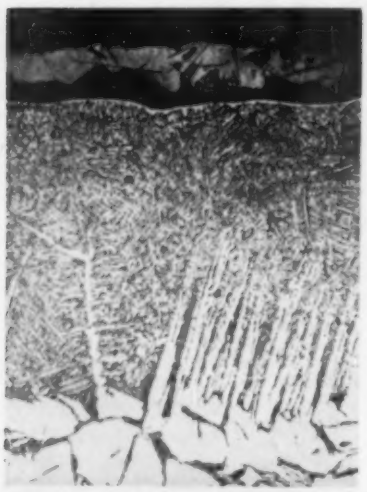

Fig. 28—Diffusion of Zircaloy and copper plate after 15 min. at 1700° F. High heating rate—× 1000. (Reduced by 47% upon reproduction)

Fig. 29—Diffusion of Zircaloy and copper plate after 15 min at 1800° F. High heating rate—× 1000. (Reduced by 47% upon reproduction)

At 1550° F, the first evidence of two molten phases occurs. Close examination of the micrograph in Fig. 25 reveals that they are intermediate phases that have melted and commenced to fill the gaps between the individual copper deposits. If the base material were pure zirconium, it would be a simple matter to specifically indicate the composition of phases that have first melted, because the 5 intermediate phases of the Zr-Cu system were clearly visible. The presence of tin in the Zircaloy makes the specific phase identifications impossible due to the absence in the literature of the ternary Zr-Cu-Sn system. Be that as it may, identification is of secondary importance. The important point is that melting was found to occur about 75–100° F below the temperature of the lowest eutectic of the zirconium-copper system (1625° F).

At 1550° F, the diffusion of copper into the Zircaloy has become evident also. This initial diffusion product appears primarily in the boundaries and crystallographic planes of Zircaloy grains and appears to be one of the molten phases. Very little bulk diffusion of the copper into the Zircaloy was yet evident at this temperature.

At a temperature of 1600° F, one more phase was noted to have melted. The deposit of copper has not yet become entirely continuous. Bulk diffusion, however, into the Zircaloy has commenced.

At 1650° F, the deposit appears as a continuous layer due to the total fusion of one more phase. Dispersed throughout the matrix of this new molten phase are the crystals of a last copper-rich, high-melting phase in the system. Diffusion appears now to be of solid-state bulk diffusion. One or two phases have disappeared due to the decrease in over-all copper content in the diffusion layers.

At 1700° F, the bulk diffusion has progressed considerably, as evidenced by the loss of more copper-rich phases. The copper-rich crystals noted at 1650° F have been almost completely dissolved in the matrix of the plate layer. Bulk diffusion has continued to a further degree.

At 1800° F, one alloy remains at the diffusion interface, which in turn is completely diffused at 1900° F into the Zircaloy.

Variation of heating rate added little of significance to the study. Very little difference in the above-discussed phenomena was evidenced after holding at temperature for similar lengths of time after slow cooling within the range of rates examined.

Summing up, it has been shown that the diffusion of solid Zircaloy into solid copper is relatively rapid even at temperatures as low as 1450° F. After 15 min, sufficient Zircaloy has diffused into the copper to form

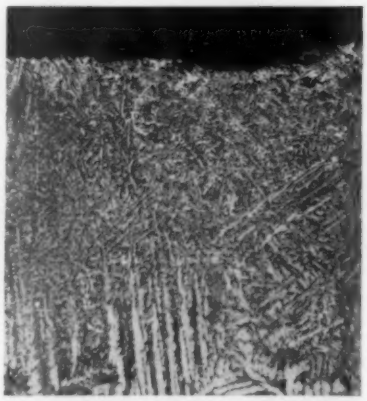

Fig. 30—Diffusion of Zircaloy and copper plate after 15 min at 1900° F. High heating rate—× 1000. (Reduced by 47% upon reproduction)

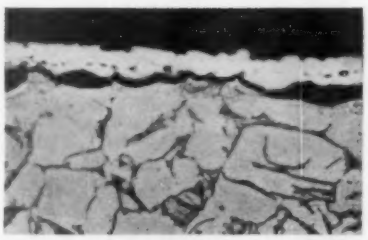

Fig. 31—Diffusion of Zircaloy and iron plate after 60 min at 1700° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

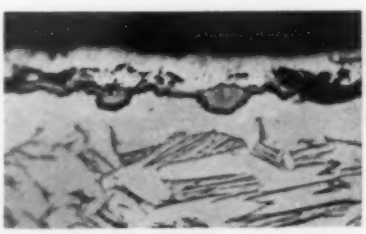

Fig. 32—Diffusion of Zircaloy and iron plate after 60 min at 1750° F. High heating rate—× 1000. (Reduced by 60% upon reproduction)

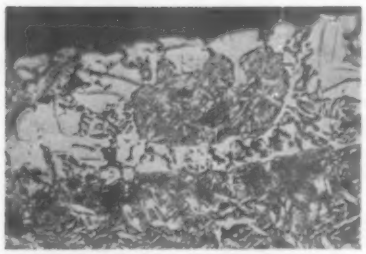

Fig. 33—Diffusion of Zircaloy and iron plate after 60 min at 1800° F. Rapid heating rate—× 1000. (Reduced by 60% upon reproduction)

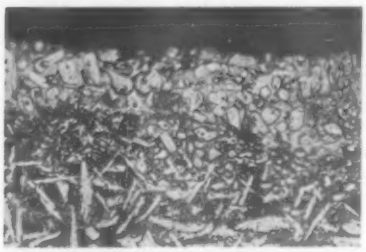

Fig. 34—Diffusion of Zircaloy and iron plate after 60 min at 1900° F. Rapid heating rate—× 1000. (Reduced by 60% upon reproduction)

phases that melt at 1550° F. Diffusion of copper into Zircaloy appears to be a slower process in that little or no penetration of the plated copper layer is noted until enough Zircaloy has diffused into the copper to form the liquid phase. At 1550° F, diffusion of the copper-rich Zr alloy has commenced via intergranular rather than bulk diffusion. At higher temperatures bulk diffusion plays an increasingly important role until this mechanism completely supersedes grain boundary penetration. Although quantitative measurements of diffusion rates were not within the scope of this investigation, the solid-state diffusion of copper through the matrix of the Zircaloy was observed to be quite rapid. The transition from intergranular diffusion to bulk diffusion is associated with the α-β transformation.

Diffusion of Zircaloy and Iron

The diffusion of iron into Zircaloy presents a simpler picture than that of copper in that the Fe-Zr system has one intermetallic compound and only one eutectic capable of melting within the range of temperatures investigated. Although tin is present in the system being discussed, the statement regarding the one eutectic capable of melting in the range of temperature investigated holds true on the basis of the metallographic examinations.

Differing from copper, no reaction or diffusion between the immersion-plated iron and Zircaloy occurs after 15 min at a temperature of as high as 1900° F. Not even with slow heating to temperature and a slow cooling, which should effectively extend the time at high temperature, was diffusion noted. Two more inherent differences between the copper plate and the iron plate were observed. First, and most striking, is the uniformity in plating thickness and the continuity of the iron plate; the copper plate consisted of isolated deposits. Secondly, the iron plate contacts the Zircaloy only at the top of asperities. Between the iron plate and the Zircaloy was a film of slate-gray, nonmetallic-appearing matter. The material was present under all iron platings examined. The composition of the slate-gray material is unknown but, if an oxide, may account for the time lag in the onset of diffusion. This hypothesis will be expanded later.

Diffusion was noted between iron and Zircaloy only after 1 hr at 1750 to 1800° F. Figures 31 through 34 are a series of photomicrographs at high magnification of the iron-Zircaloy interfaces after one hour at progressively higher temperatures. At 1700° F, no change has occurred at the interface. At 1750° F a new material appears. This material, however, is not a product of iron-Zircaloy diffusion as at these points the Zircaloy was in contact with an unknown slate-gray matter and not with iron. This new, light-gray material is believed to be the product of a reduction of the slate-gray material by the Zircaloy.

Continuing the above postulation, at 1800° F the reduction reaction apparently can be completed within 1 hr. At this temperature a considerable amount of both diffusion and melting has occurred at the interface. The large amount of liquid formed and the seeming rapidity of the diffusion are attributed to the degree of superheat over the binary eutectic temperature of the Fe-Zr (1713° F); the superheat is required to reduce the slate-gray matter between the iron and the Zircaloy. The micrograph in Fig. 33, however, is not representative of the appearance of the entire interface. At 1800° F, the diffusion of the iron and Zircaloy with subsequent melting was a local phenomenon. Some areas along the interface still retained the appearance of the 1750° F specimen with varying degrees of the reduction of the slate-gray material still in progress after 1 hr.

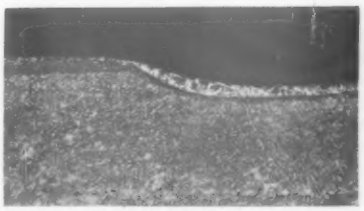

Fig. 35—Edge of plated iron spot showing reduction in volume due to iron and Zircaloy diffusion after 60 min at 1900° F. Note the flow characteristics of the molten alloy formed. Fast heating—× 150. (Reduced by 60% upon reproduction)

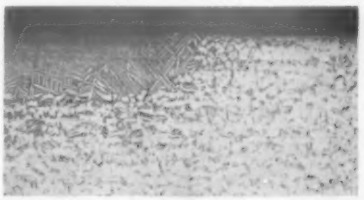

Fig. 36—Edge of plated copper spot showing little or no lateral flow or volume change after diffusion for 60 min at 1700° F. Fast heating—× 150. (Reduced by 60% upon reproduction)

In areas adjacent to the diffused and molten areas, the molten material had flowed over the iron plate, and diffusion had commenced above the plate.

At 1900° F, diffusion had progressed rapidly and the original iron plate was no longer existent. The structure, however, was not homogeneous in that numerous phases were present at the edge. The larger crystals in this example are believed to be either the high-melting, stable, Fe-Zr-(Sn?) compound shown in the binary system or the ternary θ phase. The smaller particles may be the product of the reduction process described above. Further experimentation and investigation would be required, however, before these phases can be established.

In reference to the postulated existence of the slate-gray iron oxide barrier layer, it is interesting to note that in the immersion plating of iron Fe_2O_3 was sometimes found in the plating bath.

Flow Characteristics and Related Phenomena

No flow of either iron or copper plate on the specimen was visible after heat treatment. Metallographically, however, the lateral flow of iron was found to be pronounced. The flow characteristics of iron as compared to copper on the Zircaloy surface are illustrated in Figs. 35 and 36 respectively. The specimens presented were rap-

idly heated to temperatures above which molten alloy had been observed to exist and held at temperature for 1 hr.

The large amount of flow evidenced by the iron is believed to be attributable to the degree of superheat required to reduce the slate-gray barrier layer. After the reduction reaction was completed, the temperature was sufficiently high to bring about rapid diffusion and the formation of an excess of liquid available for lateral flow. No such barrier layer exists between the copper and the Zircaloy; the melting phases could diffuse into the Zircaloy as rapidly as they were formed and at the temperature at which they formed.

It is believed that the flow of the Fe-Zr eutectic and the resulting depression in the surface of the Zircaloy is the cause of the large voids often observed in fuel elements fabricated with an iron diffusion medium. The encumbering slate-gray material more properly is considered the underlying cause of not only the large voids but also the undependability of bonds fabricated with iron. The obvious elimination of this problem will be in the development of a plating process for iron that does not result in the nonmetallic deposit.

Summary

A program on the diffusion bonding of plate-type, compartmented ceramic-fuel Zircaloy nuclear elements has been completed.

In regard to the process of edge welding and diffusion bonding under inert gas pressure, the following process phases were investigated and satisfactory procedures presented: coating of urania fuel with graphite to inhibit the UO_2-Zircaloy reaction, inert-gas arc welding of edges of elements and diffusion bonding furnace procedures, including the effects of temperature, time, plating thickness and gas pressure.

Based on the mechanical properties and corrosion resistance of bonded elements and on metallographic observations, copper was superior to iron as the diffusion bonding medium. Copper-bonded elements having the best combination of properties had a plated copper thickness of 0.1 mil and were diffusion-bonded at 1900° F under 30 psi of helium for periods from $^1/_2$ to 2 hr. The behavior of elements plated with iron was undependable, and voids generally formed in the bond.

Two geometries of fuel receptacle sheet were studied. The effect of geometry on mechanical properties of the elements was discussed in detail, and the superiority of one type over the other clearly shown (i.e., superiority in regard to bond strength requirements and fabrication latitude).

A metallographic study of copper- and iron-plated disks on Zircaloy showed the effects of temperature, time, and heating and cooling rates on the interface reactions. As-plated copper is discontinuous on the Zircaloy, whereas the as-plated iron is a continuous film. With copper, intermediate phases are evident after 15 min at 1450° F, molten material after 15 min at 1550° F; after 15 min at 1650° F the alloyed copper plate was continuous over the Zircaloy surface.

In the case of iron, a slate-gray layer is observed between the iron plate and the Zircaloy. The layer is postulated to be a barrier layer of oxide which inhibits diffusion and must be reduced before diffusion can occur. Fifteen minutes at temperatures as high as 1900° F caused no obvious diffusion between the plate and the Zircaloy. The barrier layer showed a visible change after 1 hr at 1750° F, and melting of a eutectic phase occurred after 1 hr at 1800° F.

The metallographic study bore out the dependability of copper and the undependability of iron as the diffusion medium.

Acknowledgments

This program was sponsored by the Westinghouse Atomic Power Division, and the authors appreciate their permission, and that of the Naval Reactors Branch, to publish the findings. In addition, the guidance of E. F. Losco and B. Lustman of Westinghouse is gratefully acknowledged.

Author's Note

The conclusions derived from this investigation are understood by the authors to be subject to modification by later investigations performed at Bettis Westinghouse, in regard to long-time corrosion resistance of diffusion bonded elements. Details of these investigations are not known to the present authors, but will undoubtedly appear in the literature.

References

1. Losco, E. F., Fischer, R. L., Saunders, N. T., and Wolfe, R. H., "Plate-Type UO_2-Bearing Fuel Elements for the PWR Core 2 Blanket." Presented at Gatlinburg Fuel Element Conference, WAPD-T-801, Gatlinburg, Tenn. (May 1958). Glatter, J., Losco, E. F., Hurford, W. J., Theilacker, J. S., Fischer, R. L., Saunders, N. T., and Wolfe, R. H., "The Manufacture of PWR Blanket Fuel Elements Containing High Density Uranium Dioxide," Presented at the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, Switzerland (Sept. 1958).

2. Cain, F. M., Jr., "The Chemical Displacement Plating of Zirconium and Zircaloy," WAPD-BT-6 (Jan. 1958). Kohan, L., "Immersion Plating on Zircaloy-2," *Metal Finishing* (Nov. 1959).

WRC Bulletin No. 66

"Interpretive Report on Operating Conditions for Nuclear Pressure Vessels" by K. F. Smith

Welding Research Council Bulletin #66 published in January 1961 was prepared in order to assist designers of nuclear pressure vessels to understand some of the problems that would be encountered in service. It was hoped that a description of the operating conditions would provide a good background of information to act as a basis on which to design such pressure vessels. This Interpretive Report describes the kinds of operating conditions, along with the principal types of nuclear reactors. Information is provided on the pressurized water reactor, the boiling water reactor and the aqueous homogeneous reactor. The subjects of pressure, temperature, corrosion and irradiation are covered in this Report.

The price of this Bulletin is $1.00 and single copies may be purchased through the American Welding Society, 33 West 39th Street, New York 18, N. Y. Quantity lots may be purchased through the Welding Research Council, 29 West 39th Street, New York 18, N. Y.

The Nature of the Diffusion of Brazing Alloy Elements into Heat-Resisting Alloys

Diffusion reactions as related to high-temperature alloy brazing are determined for boron, carbon, chromium, iron, nickel and silicon

BY W. FEDUSKA

SYNOPSIS. A microstructural and microhardness study was made of the diffusion of single and binary combinations of elements, present in commercial high-temperature brazing alloys, into heat-resisting alloys. Data obtained on 105 diffusion samples isolated the effects of individual diffuser elements during brazing alloy base metal interface reactions.

Introduction

In a previous investigation,[1] microstructural and microhardness characteristics were analyzed for brazed joint interfaces of six types of high-temperature base metals and three types of high-temperature brazing alloys. This investigation, part of a program aimed at learning the fundamentals which control brazed joint formation, led to a qualitative understanding of the diffusion mechanisms which were encountered and the microstructures which were produced during high-temperature alloy brazing. During this investigation, the lack of analytical equipment or techniques prevented any quantitative determination of the nature of the reacted grain boundary constituents or solid solution regions at the brazed joint interfaces. Therefore, an experiment was designed in which the effects of individual elements present in high-temperature brazing alloy—and their binary combinations—might be isolated and determined. In this experiment boron, carbon, chromium, iron, nickel and silicon were permitted to diffuse as single elements and as binary combinations into a variety of heat-resisting alloys. Samples were studied microscopically to determine the nature of diffusion reactions. These data could then be related to diffusion reaction structures produced by high-temperature alloy brazing.

W. FEDUSKA is with the Materials Laboratories, Westinghouse Electric Corp., E. Pittsburgh, Pa.

Table 1—Source Materials for Diffuser-element Powders

Boron	Boron powder, from Westinghouse APD
Carbon	Graphite powder
Chromium	Electrolytic chromium, −325 mesh, Charles Hardy, Inc. (99.98–99.85% chromium)
Iron	Plast iron, −325 mesh, National Radiator Co. (99.96–99.70% iron)
Nickel	Plast nickel, −325 mesh, Grade F23, National Radiator Co. (99.95–99.60% nickel)
Silicon	Purified silicon powder, −325 mesh, Electro Met. Corp. (99.80–98.20% silicon)

Materials

Pure powders of boron, chromium, iron, nickel and silicon were used in this experiment. Graphite powder was utilized in the carbon diffusion studies. In Table 1 the sources of these metal powders have been listed. AISI 410, AISI 347, Alloy 3, Alloy 4 and Alloy 5 plates, about 1 x 1 x $^1/_8$ in., were placed in contact with the various single-element powders and binary-element combinations of these powders, prior to the diffusion treatments. Table 2 lists the compositions of these base materials.

Procedure

In one series of diffusion tests, single-element powders of elements present in commercial high-temperature brazing alloys were used. The powder of a particular diffuser element was preplaced into a Norton alundum boat, having a 1- x 6- x $^1/_2$-in. well. When this well was half filled, polished (No. 1 metallographic paper finish) and degreased, plates of the various high-temperature alloy materials were horizontally positioned about $^1/_4$ in. apart on the preplaced powder. Then additional powder was heaped over the alloy plates until the alundum boat was filled—Fig. 1. This procedure was also used when binary-element powder mixtures (weighed to produce a 50:50 atomic percent mixture) were preplaced. After the charging operation, the boats were placed on a vibrating table and vibrated for about 15 min. The vibration packed the powder in contact with the high-temperature alloy plates. When the vibration had been completed, boats were grouped according to a predetermined diffusion procedure, and each group was placed onto a stainless steel tray and charged into an Inconel retort. Some titanium pellets were placed inside the retort, near the gas inlet region, to react with trace contaminators which might enter the retort along with the dried hydrogen. This retort was sealed and then purged by passing dry hydrogen (about −58° F dewpoint) through the chamber for about $^1/_2$ hr. After the purging

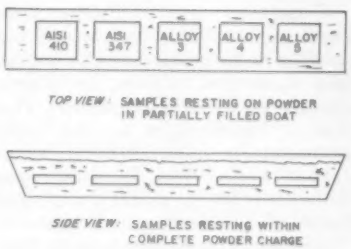
AISI 410
AISI 347
ALLOY 3
ALLOY 4
ALLOY 5
TOP VIEW: SAMPLES RESTING ON POWDER IN PARTIALLY FILLED BOAT
SIDE VIEW: SAMPLES RESTING WITHIN COMPLETE POWDER CHARGE

Fig. 1—Method for positioning base materials into powders of diffuser-elements. Shaded areas represent powder-filled regions of the alundum boat

Table 2—Compositions of High-temperature Alloys used in the Diffusion Experiments

Alloy	Base metals: Designation	Composition, %: C	Mn	Si	Cr	Ni	Co	Mo	W	Nb Ta	Ti	Al	Fe
AISI 410[a]	Martensitic stainless	0.15 max.	..	..	11.5–13.5	...	...	..	...	...	..	..	Bal.
AISI 347[a]	Austenitic stainless	0.08 max.	..	..	17.0–19.0	9.0–13.0	...	..	...	0.80 min.	..	..	Bal.
Alloy 3[b]	Iron-base, high-temp. alloy	0.03	0.8	0.8	13.5	26.0	...	3.0	...	...	1.6	0.1	Bal.
Alloy 4[b]	Nickel-base, high-temp. alloy	0.04	0.7	0.3	15.0	Bal.	...	..	...	0.9	2.5	0.9	7.0
Alloy 5[b]	Cobalt-base, high-temp. alloy	0.10	1.5	0.7	20.0	10.0	Bal.	..	15.0	...	..	..	1.0

[a] Nominal composition. [b] Actual composition.

operation, the retort was charged into a globar furnace. The diffuser-elements were then permitted to react in a protective atmosphere of dry hydrogen with the base materials at a predetermined temperature and time.

Generally, the diffusion temperature was selected below the melting temperature of the particular elemental powder or binary-element powder combination. This was a temperature in the high-temperature alloy brazing range (about 1740–2190° F) which was sufficiently low to enable grouping of some of the test runs together—Table 3. The single-element powders—boron, chromium, iron, nickel and silicon—were heated at 2010° F for 78 hr. When complete fusion of all the base metals occurred in contact with boron at this 2010° F treatment, another boat was prepared. In this repeat test, the samples were heated in contact with boron for only 1 hr at 1650° F. This treatment produced satisfactory boron-diffusion samples for the metallographic and microhardness investigations. The boat containing graphite was heated at 1920° F for 10 hr to produce satisfactory carbon-diffusion specimens for the investigation.

Following the single-element powder-diffusion tests, diffusion tests were run with binary-element powders. These binary-element powder combinations included: boron-carbon, boron-chromium, boron-iron, boron-nickel, boron-silicon, carbon-chromium, carbon-iron, carbon-nickel, carbon-silicon, chromium-iron, chromium-nickel, chromium-silicon, iron-nickel, iron-silicon and nickel-silicon. The alundum boats which contained boron-chromium boron-iron, boron-nickel, boron-silicon, chromium - iron, chromium-nickel, chromium - silicon, iron-nickel, iron-silicon and nickel-silicon powders were heated at 1740° F for 24 hr; the boats which contained boron - carbon, carbon - chromium, carbon-iron, carbon-nickel and carbon-silicon were held at 1920° F for 4 hr.

After each batch diffusion treatment, the retort was removed from the furnace and the charge was cooled in dry hydrogen. Upon cool-down to room temperature, the charge was removed from the retort and the high-temperature alloy plates were separated from the powders. The samples were cleaned to remove any loose powder and were sectioned transversely for microscopic examination. After the samples were examined for evidence of diffusion, microhardness variations were obtained in the reaction zones. These data were compared with interface reaction structures and microhardness data previously obtained on joint regions between commercial high-temperature brazing alloys and the same base materials.

The maximum visible depth of diffusion penetration was also measured. Depth of penetration measurements were made at × 250 magnification by recording the Microton stage travel of the Tukon microhardness tester from the sample surface to the deepest visible diffusion penetration. The determination of diffusion coefficients of the individual elements was not considered to be within the scope of this experiment, and the samples were not designed toward this objective.

Results and Discussion

The results of the microscopic examination of the diffusion specimens are summarily illustrated in Figs. 2 through 12. In Table 4, the microhardness data which were obtained on some of the diffusion samples have been summarized. In Table 5, measured depths of diffusion penetration have been recorded.

Table 3—Element Melting Points, Eutectic Temperatures of Binary Alloys, and Diffusion Cycles Used on Various Diffusion Test Combinations

Diffuser elements	Melting temperature, ° F	Diffusion temp., ° F	Diffusion time, hr
B	4172 ± 540	1652	1
C	6692 ± 180	1922	10
Cr	3434	2012	78
Fe	2804	2012	78
Ni	2650	2012	78
Si	2606	2012	78
	Eutectic temperature, ° F (minimum, where more than one)		
B-C	[a]	1922	4
B-Cr	[a]	1742	24
B-Fe	2100	1742	24
B-Ni	1814	1742	24
B-Si	[a]	1742	24
C-Cr	2730	1922	4
C-Fe	2093	1922	4
C-Ni	2406	1922	4
C-Si	[b]	1922	4
Cr-Fe	2746[c]	1742	24
Cr-Ni	2453	1742	24
Cr-Si	~2408	1742	24
Fe-Ni	2618[c]	1742	24
Fe-Si	2192	1742	24
Ni-Si	1769	1742	24

[a] No phase diagram. [b] Not clearly known. [c] Minimum point.

Boron Diffusion

Boron rapidly diffuses along the grain boundaries of the austenitized AISI 410 and austenitic AISI 347, Alloy 3 and Alloy 4 base metals. Some volume diffusion of boron into the surface grains of these base metals can be seen in Figs. 2A through 2D. A boron-rich layer can be observed on the surfaces of these same samples. In Alloy 5, the darkened and widened grain boundary regions in the sample surface grains indicate regions of boron penetration—Fig. 2E.

Boron grain boundary diffusion has been found in high-temperature alloy brazing, where boron-containing brazing alloys, as Nicrobraz, have been reacted with various ferritic and austenitic high-temperature alloys.[1] In these reactions, boron penetrates into the grain boundaries of the base metal and forms a boron compound network in these boundaries. Boron also irrigates into the grains surrounded by the boron grain boundary network.[1]

In Table 4 the increase in hardness in the surface regions of the base metals, resulting from boron diffusion, is shown. These data are listed in Group 1 of this exhibit. In Table 5, the maximum visible depth of penetration* by diffuser elements have been listed. From these data, maximum visible diffusion by boron (0.0036 in.) occurred in Alloy 4 base metal for the 1-hr diffusion treatment at 1650° F.

Carbon Diffusion

Figure 3 shows carbon diffusion into the various base metals. For the diffusion treatment of 10 hr at 1920° F, carbon has diffused to a considerable depth, primarily along the grain boundaries, of all the base materials. The data of Table 5 indicates that carbon diffusion has varied from 0.0304 in. in Alloy 4 to 0.0680 in. in Alloy 5. Considerable irrigation of carbon into the base metal grains, from the grain boundary regions, can also be observed by the darkened regions surrounding the martensitic grains of the AISI 410 base metal and by the heavy carbide formations in the grains of the AISI 347, Alloy 3, Alloy 4, and Alloy 5. Carbide formation has occurred along twin planes of the austenitic grains of Alloy 5, while cubic carbides can be observed within these grains—Fig. 3E. Determination of the nature of these carbides was not included in this investigation. The high-carbon concentration has apparently produced a carbon-rich layer at the surface of the AISI 410. This region may be untransformed austenite. (Considerable solution of diffused carbon in this area would tend to make the high carbon - chromium - iron austenite transformation very sluggish.) It may account for the lower hardness of this surface region (216 KHN) when compared with the hardness

* Recent autoradiographic techniques[2] have shown that the depth of diffusion penetration can be greater than suspected by the visible diffusion penetration reactions. Therefore, visible depth measurements can only be considered as approximate values.

Table 4—Microhardness Data Obtained on Diffusion Samples

Knoop Hardness Numbers (KHN) obtained at 0.1 kg load, 10.25 mm objective

Location of hardness impressions:

A—at the interface

B—at the region where visible diffusion reaction ceases

C—at the central region of the base metal

D—surface reaction products, where measurable, as eutectic structures, solid solution bands

Group	Test combination element(s)—base metal	KHN, at location A	B	C	D
1	B-AISI 410	317	298	267	...
1	B-AISI 347	282	201	188	...
1	B-Alloy 3	240	201	179	...
1	B-Alloy 4	336	326	347	...
1	B-Alloy 5	317	326	283	...
2	C-AISI 410	216	672	526	...
2	C-AISI 347	253	246	259	...
2	C-Alloy 3	157	179	228	...
2	C-Alloy 4	298	347	395	...
2	C-Alloy 5	592	470	370	...
3	Cr-AISI 410	206	183	161	...
3	Cr-AISI 347	423	347	211	...
3	Cr-Alloy 3	233	222	192	...
3	Cr-Alloy 4	326	222	382	...
3	Cr-Alloy 5	336	370	395	...
4	Fe-AISI 410	139	154	154	...
4	Fe-AISI 347	175	188	192	...
4	Fe-Alloy 3	179	168	164	...
4	Fe-Alloy 4	347	253	358	...
4	Fe-Alloy 5	267	358	358	...
5	Ni-AISI 410	358	259	175	...
5	Ni-AISI 347	228	216	188	...
5	Ni-Alloy 3	240	240	222	...
5	Ni-Alloy 4	347	253	382	...
5	Ni-Alloy 5	253	307	358	...
6	Si-AISI 410	453	298	157	...
6	Si-AISI 347	192	...	201	416
6	Si-Alloy 3	259	157	148	...
6	Si-Alloy 4	547	423	347	...
6	Si-Alloy 5	382	188	179	...
7	BC-AISI 410	408	395	298	...
7	BC-AISI 347	437	326	216	1951
7	BC-Alloy 3	298	246	192	307
7	BC-Alloy 4	274	290	395	735
7	BC-Alloy 5	592	506	453	526
8	BFe-AISI 410	259	408	336	...
8	BFe-AISI 347	408	228	192	...
8	BFe-Alloy 3	283	201	179	...
8	BFe-Alloy 4	592	437	336	...
8	BFe-Alloy 5	470	382	395	...
9	CCr-AISI 410	592	617	735	...
9	CCr-AISI 347	228	298	253	...
9	CCr-Alloy 3	246	228	168	...
9	CCr-Alloy 4	259	267	336	...
9	CCr-Alloy 5	358	382	307	...
10	CFe-AISI 347	735	526	437	...
11	CNi-AISI 347	326	347	282	...
12	CSi-AISI 410	592	702	702	437
12	CSi-AISI 347	453	283	188	423
12	CSi-Alloy 3	283	246	216	453
12	CSi-Alloy 4	470	298	358	672
12	CSi-Alloy 5	317	358	370	...
13	FeSi-AISI 410	283	326	370	233
13	FeSi-AISI 347	216	201	201	526

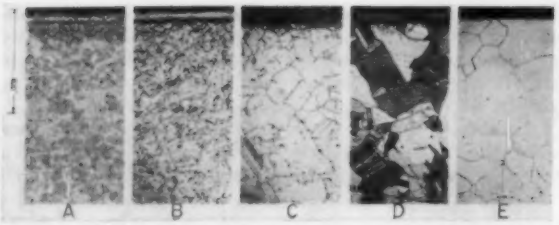

Fig. 2—Effect of boron diffusion into various high-temperature alloys; samples were heated for 1 hr at 1650° F: A—AISI—410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 68% on reproduction)

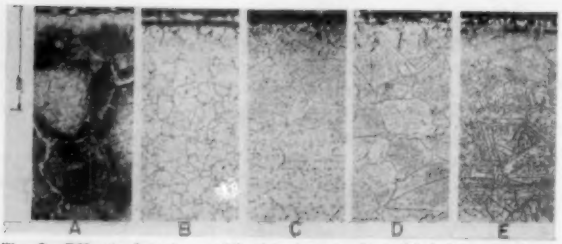

Fig. 3—Effect of carbon diffusion into various high-temperature alloys; samples were heated for 10 hr at 1920° F: A—AISI—410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 68% on reproduction)

at the carbon diffusion front (672 KHN) in the AISI 410 sample. Hardness data of the carbon diffusion samples have been listed in Table 4, Group 2. Carbides appear to partially outline the grain boundary regions of the AISI 410 and carbon diffusion appears to have darkened the AISI 410 grains in the irrigated regions next to the grain boundaries—Fig. 3A. This effect prevailed throughout the base metal. Volume diffusion of carbon into the surface regions of the AISI 410 caused a complete darkening of the surface grains.

Chromium Diffusion

Chromium diffuses into AISI 410, AISI 347, Alloy 3, Alloy 4 and Alloy 5 primarily by a volume diffusion mechanism—Fig. 4. Chromium has formed a solid solution bond with the base metal elements. In the chromium-AISI 347 reaction, irregularly-shaped pale green particles (possibly sigma phase) appeared in the reaction solid solution region at the surface of the base metal. In this investigation no attempt was made to analyze the solid solution regions, or the particles which were indicative of sigma phase, to determine their exact nature.

Chromium diffusion into Alloy 3 and Alloy 4 produced solid solutions which became supersaturated, upon cool-down, and resulted in chromium compounds of titanium and/or aluminum precipitating in the sample surface grain boundary and grain regions of these alloys—Figs. 4C and 4D. In Alloy 3, the irregular-shaped, precipitated particles were orange. At the surface region of the Alloy 4 sample, orange, hexagonal-shaped compound particles precipitated out of solution from the chromium-enriched diffusion region. Hansen[3] cites work by Austin and Doig in which a high-temperature form of $TiCr_2$ is hexagonal and is produced between 1830–2400° F. The 2010° F diffusion temperature of the chromium-Alloy 4 sample falls within this temperature range. The chromium intermetallic compound particles appeared to a depth of 0.0440 in. in Alloy 3, while the particles in the Alloy 4 were evident to a depth of 0.0080 in. after the samples were heated for 78 hr at 2010° F. The chromium-Alloy 5 sample exhibited only a very narrow region of solid solution formation on the sample surface—Table 5.

Chromium diffusion produced an increase in hardness in the surface reaction regions in AISI 410, AISI 347, Alloy 3 and Alloy 4. The hardness data obtained on Alloy 5 showed that chromium diffusion caused a decrease in hardness in the resultant solid solution at the surface of this sample. The chromium diffusion, hardness data have been summarized in Group 3 of Table 4.

Iron Diffusion

Iron diffused into all the base alloys by a volume diffusion mechanism. The iron diffusion produced an iron-base alloy region on the surface of these base materials, as shown in Fig. 5. These iron-rich surfaces were readily attacked by the Fry's reagent. Excepting the Alloy 4 sample, the iron diffusion produced a softening of the surface reaction regions of the base materials. The hardness values obtained in these samples are listed in Group 4 of Table 4.

Nickel Diffusion

Volume diffusion of nickel can be observed in the solid solution reaction interfaces of AISI 410, AISI 347, Alloy 3, Alloy 4, and Alloy 5 shown in Fig. 6. Nickel diffusion into Alloy 3 has resulted in the precipitation from solid solution, upon cool-down from diffusion temperature, of both orange and purple compound particles. Nickel diffusion produced an increase in hardness in the reaction solid solution regions of AISI 410, AISI

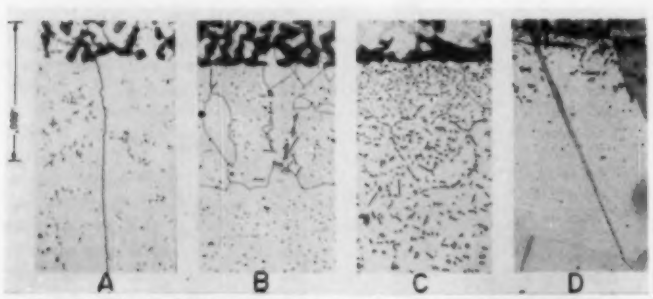

Fig. 4—Effect of chromium diffusion into various high-temperature alloys; samples were heated for 78 hr at 2010° F: A—AISI 410; B—AISI 347; C—Alloy 3; D—Alloy 4. Fry's etch. × 200 (reduced 70% on reproduction)

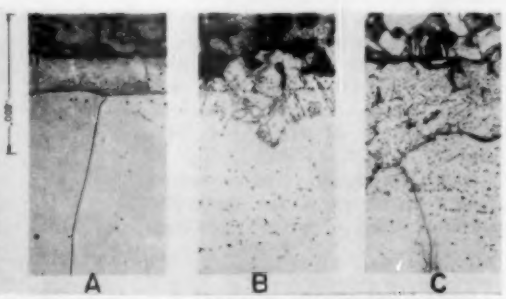

Fig. 5—Effect of iron diffusion into various high-temperature alloys; samples were heated for 78 hr at 2010° F: A—AISI 410; B—AISI 347; C—Alloy 3. Fry's Etch. × 200 (reduced 65% on reproduction)

347 and Alloy 3 and a decrease in hardness in Alloy 5—Group 5 of Table 4. Maximum diffusion of nickel (0.0128 in.) occurred in the Alloy 3 sample—Table 5.

Silicon Diffusion

In Fig. 7 the diffusion of silicon into high-temperature alloy is shown. Silicon migrated into the various base metals, primarily, by volume diffusion. Silicon diffusion into AISI 410 produced a hardening of the surface region (453 KHN) compared with a hardness of 157 KHN for the unaffected AISI 410 base metal. An iron-silicon solid solution formed at the surface of the AISI 347 sample—Fig. 7A. The hardness of this solid solution was 416 KHN, compared with 201 KHN for the base metal. Grain boundary diffusion of silicon into Alloy 3 produced some silicide compounds in these regions while volume diffusion of silicon into this alloy produced silicon-rich solid solution and an eutectic region on the sample surface—Fig. 7B. Since iron-silicon and chromium-silicon eutectics form above the 2010° F diffusion temperature which was used on the sample and nickel-silicon eutectics form at 1710 and 1772° F, this eutectic must be comprised, primarily of nickel-silicon. The hardness of the solid solution region, near the sample surface, was 259 KHN compared with 148 KHN for the Alloy 3 base metal.

The volume diffusion reaction of silicon into Alloy 4 is shown in Fig. 7C. Here, silicon has diffused into the Alloy 4 in a concentration great enough to produce a liquid eutectic at the 2010° F diffusion temperature. This eutectic is again, primarily, one of the low-melting eutectics of nickel and silicon. The resultant microstructure indicates nickel-silicon rich solid solution regions, surrounded by an eutectic which is comprised of nickel-silicon rich solid solution and silicide intermetallic compound. Darkly-etched areas at the interface region of the base metal indicate incipient silicon volume diffusion. The high hardness of the eutectic regions (547 KHN) suggests that hard silicides have formed —Group 6, Table 4. At the center of the Alloy 4 sample, where silicon had not diffused, a hardness of 347 KHN was obtained.

Boron-carbon Diffusion

The boron-carbon diffusion reactions with the various base metals are shown in Fig. 8. For comparison purposes, separate diffusion reactions by boron and carbon are shown in Figs. 2 and 3. In Fig. 8A, boron grain boundary diffusion is evident by the white compound formation* in the AISI 410 prior-austenite grain boundaries while grain boundary and volume diffusion by boron and carbon have produced a darkening of the surface grain regions. Heavy boron and/or carbon diffusion has also occurred along the austenite grain boundaries of AISI 347, Alloy 3, Alloy 4 and Alloy 5. Volume diffusion of boron and/or carbon is evident in the AISI 347, Alloy 3, Alloy 4, and Alloy 5 surface grains. Irrigation of boron and/or carbon from the grain boundaries has resulted in intermetallic boride, carbide, or boro-carbide compound formation in the grains of the AISI 347, Alloy 3, Alloy 4 and Alloy 5 samples—Figs. 8B through 8E. The diffusion of boron and carbon produced an increased hardness in all the base metal surface regions, as shown by the data in Group 7 of Table 4. Extremely-high hardnesses were detected in the surface reaction products of AISI 347 (1951 KHN) and Alloy 4 (735 KHN). Since these values exceeded hardness results produced by separate diffusion of boron and carbon, they indicate the presence of boro-carbide intermetallic compound(s) in the reaction zone. Maximum diffusion penetration by boron and carbon occurred in the AISI 347 and Alloy 4 samples—Table 5.

* This structure was noted in the samples only when boron diffusion occurred.

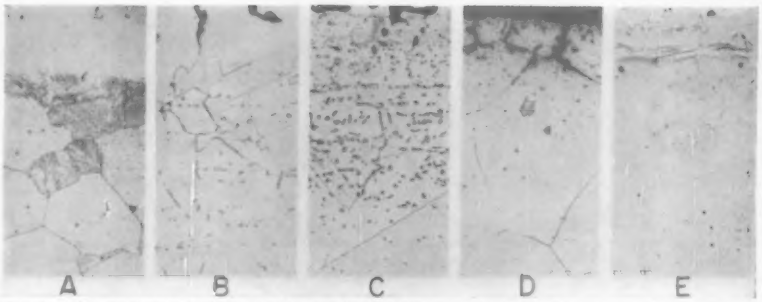

Fig. 6—Effect of nickel diffusion into various high-temperature alloys; samples were heated for 78 hr at 2010° F: A—AISI 410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 50% on reproduction)

Boron-iron Diffusion

Joint diffusion by boron and iron into the base materials is shown in Fig. 9. For comparison, the separate diffusion of each of these elements is shown in Figs. 2 and 5. In the boron-iron diffusion samples, boron has diffused along the grain boundaries of the AISI 410, AISI 347, Alloy 3 and Alloy 4 and has reacted with base metal elements to form intermetallic borides. Incipient grain boundary diffusion and volume diffusion by boron are evident in the surface microstructure of the Alloy 5 base metal—Fig. 9E. Incipient volume diffusion and irrigation of boron from the grain boundaries has darkened the grains in the surface region of the Alloy 3

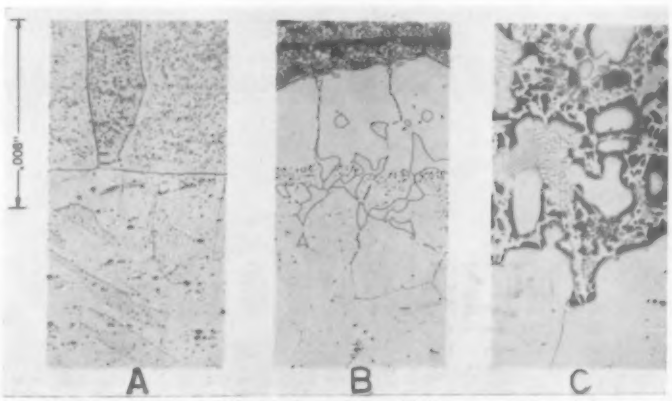

Fig. 7—Effect of silicon diffusion into various high-temperature alloys; samples were heated for 78 hr at 2010° F: A—AISI 347; B—Alloy 3; C—Alloy 4. × 200 (reduced 65% on reproduction)

Table 5—Depth of Penetration of Various Diffuser elements into Various High-temperature Alloys

Base metal	Diffuser element(s)	Diffusion temp., F	Diffusion time, hr	Maximum visible depth of penetration, in.
AISI 410	Boron	1652	1	0.0024
AISI 347	Boron	1652	1	0.0020
Alloy 3	Boron	1652	1	0.0032
Alloy 4	Boron	1652	1	0.0036
Alloy 5	Boron	1652	1	Not measurable[a]
AISI 410	Carbon	1922	10	0.0676[b]
AISI 347	Carbon	1922	10	0.0460[b]
Alloy 3	Carbon	1922	10	0.0320
Alloy 4	Carbon	1922	10	0.0304
Alloy 5	Carbon	1922	10	0.0680[b]
AISI 410	Chromium	2012	78	Not measurable[a]
AISI 347	Chromium	2012	78	0.0076
Alloy 3	Chromium	2012	78	0.0440
Alloy 4	Chromium	2012	78	0.0080
Alloy 5	Chromium	2012	78	Not measurable[a]
AISI 410	Iron	2012	78	0.0020
AISI 347	Iron	2012	78	0.0040
Alloy 3	Iron	2012	78	Not measurable[a]
Alloy 4	Iron	2012	78	Not measurable
Alloy 5	Iron	2012	78	Not measurable
AISI 410	Nickel	2012	78	0.0012
AISI 347	Nickel	2012	78	0.0110
Alloy 3	Nickel	2012	78	0.0128
Alloy 4	Nickel	2012	78	Not measurable[a]
Alloy 5	Nickel	2012	78	0.0010
AISI 410	Silicon	2012	78	Not measurable
AISI 347	Silicon	2012	78	0.0336
Alloy 3	Silicon	2012	78	0.0060
Alloy 4	Silicon	2012	78	Not measurable
Alloy 5	Silicon	2012	78	Not measurable
AISI 410	Boron-carbon	1922	4	0.0176
AISI 347	Boron-carbon	1922	4	0.0428
Alloy 3	Boron-carbon	1922	4	0.0232
Alloy 4	Boron-carbon	1922	4	0.0400[b]
Alloy 5	Boron-carbon	1922	4	0.0112
AISI 410	Boron-chromium	1742	24	0.0056
AISI 347	Boron-chromium	1742	24	0.0052
Alloy 3	Boron-chromium	1742	24	0.0096
Alloy 4	Boron-chromium	1742	24	0.0048
Alloy 5	Boron-chromium	1742	24	0.0044
AISI 410	Boron-iron	1742	24	0.0076
AISI 347	Boron-iron	1742	24	0.0054
Alloy 3	Boron-iron	1742	24	0.0080
Alloy 4	Boron-iron	1742	24	0.0128
Alloy 5	Boron-iron	1742	24	0.0032
AISI 410	Boron-nickel	1742	24	0.0080
AISI 347	Boron-nickel	1742	24	0.0064
Alloy 3	Boron-nickel	1742	24	0.0100
Alloy 4	Boron-nickel	1742	24	0.0046
Alloy 5	Boron-nickel	1742	24	0.0060
AISI 410	Boron-silicon	1742	24	0.0084
AISI 347	Boron-silicon	1742	24	0.0056
Alloy 3	Boron-silicon	1742	24	0.0134
Alloy 4	Boron-silicon	1742	24	0.0152
Alloy 5	Boron-silicon	1742	24	0.0048
AISI 410	Carbon-chromium	1922	4	Not measurable[c]
AISI 347	Carbon-chromium	1922	4	0.0448[b]
Alloy 3	Carbon-chromium	1922	4	0.0420
Alloy 4	Carbon-chromium	1922	4	0.0368
Alloy 5	Carbon-chromium	1922	4	0.0128
AISI 410	Carbon-iron	1922	4	0.0680[b]
AISI 347	Carbon-iron	1922	4	0.0452[b]
Alloy 3	Carbon-iron	1922	4	0.0444[b]
Alloy 4	Carbon-iron	1922	4	0.0464
Alloy 5	Carbon-iron	1922	4	0.0580
AISI 410	Carbon-nickel	1922	4	Not measurable[c]
AISI 347	Carbon-nickel	1922	4	0.0264
Alloy 3	Carbon-nickel	1922	4	0.0204
Alloy 4	Carbon-nickel	1922	4	0.0280
Alloy 5	Carbon-nickel	1922	4	0.0300
AISI 410	Carbon-silicon	1922	4	0.0150
AISI 347	Carbon-silicon	1922	4	0.0064
Alloy 3	Carbon-silicon	1922	4	0.0296
Alloy 4	Carbon-silicon	1922	4	0.0356
Alloy 5	Carbon-silicon	1922	4	0.0082
AISI 410	Chromium-iron	1742	24	Not measurable[d]
AISI 347	Chromium-iron	1742	24	Not measurable[d]
Alloy 3	Chromium-iron	1742	24	Not measurable[d]
Alloy 4	Chromium-iron	1742	24	Not measurable[d]
Alloy 5	Chromium-iron	1742	24	Not measurable[d]
AISI 410	Chromium-nickel	1742	24	Not measurable[d]
AISI 347	Chromium-nickel	1742	24	Not measurable[d]
Alloy 3	Chromium-nickel	1742	24	Not measurable[d]
Alloy 4	Chromium-nickel	1742	24	Not measurable[d]
Alloy 5	Chromium-nickel	1742	24	Not measurable[d]
AISI 410	Chromium-silicon	1742	24	0.0076
AISI 347	Chromium-silicon	1742	24	0.0032
Alloy 3	Chromium-silicon	1742	24	Not measurable[d]
Alloy 4	Chromium-silicon	1742	24	Not measurable[d]
Alloy 5	Chromium-silicon	1742	24	Not measurable[d]
AISI 410	Iron-nickel	1742	24	0.0020
AISI 347	Iron-nickel	1742	24	0.0014
Alloy 3	Iron-nickel	1742	24	Not measurable[a]
Alloy 4	Iron-nickel	1742	24	Not measurable[a]
Alloy 5	Iron-nickel	1742	24	Not measurable[a]
AISI 410	Iron-silicon	1742	24	0.0072
AISI 347	Iron-silicon	1742	24	0.0024
Alloy 3	Iron-silicon	1742	24	0.0068
Alloy 4	Iron-silicon	1742	24	0.0052
Alloy 5	Iron-silicon	1742	24	0.0000
AISI 410	Nickel-silicon	1742	24	0.0092
AISI 347	Nickel-silicon	1742	24	0.0032
Alloy 3	Nickel-silicon	1742	24	0.0003
Alloy 4	Nickel-silicon	1742	24	Not measurable[a]
Alloy 5	Nickel-silicon	1742	24	Not measurable[a]

[a] No evident diffusion at diffusion interface. [b] Complete base metal penetration, to center of specimen. [c] Martensitic structure masks carbon diffusion. [d] Incipient solid solution formation.

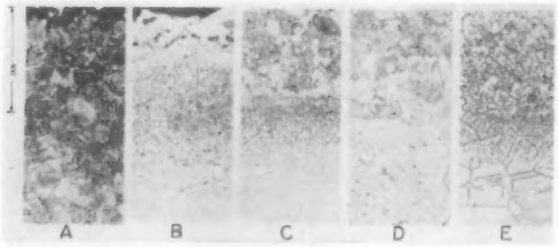

Fig. 8—Effect of boron-carbon diffusion into various high-temperature alloys; samples were heated for 4 hr at 1920°F: A—AISI 410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 68% on reproduction)

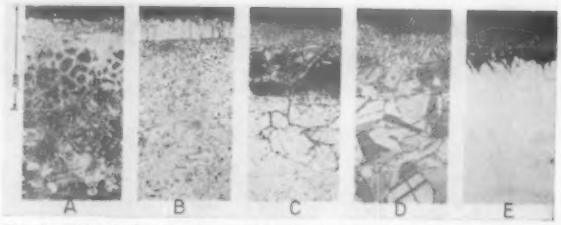

Fig. 9—Effect of boron-iron diffusion into various high-temperature alloys; samples were heated for 24 hr at 1740°F: A—AISI 410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 68% on reproduction)

samples—Fig. 9C; also compare with Fig. 2C. In Alloy 4, the deep boron diffusion has produced borides in the grain boundaries and along crystallographic slip planes within the grains—Fig. 9D. A boron-iron rich layer appears to have formed on the surface of the AISI 347 sample—Fig. 9B. No volume diffusion by iron was manifest in the other base metals after the diffusion treatment of 24 hr at 1740° F. (Compare Fig. 9 with Fig. 5.)

Boron diffusion has increased the surface hardness of all the base metals—Group 8 of Table 4. Maximum boron diffusion occurred to a visible depth of 0.0128 in. in the Alloy 4 sample—Table 5.

Diffusion reaction structures produced by binary-element combinations of boron-chromium, boron-nickel and boron-silicon were basically of a nature similar to those produced by the boron-iron reactions. In these 1740° F tests, boron rapidly penetrated along the base metal grain boundaries and irrigated into the base metal grains. Chromium, nickel and silicon slowly diffused into the base metal surface grains by a volume diffusion mechanism. For the boron-chromium and born-nickel tests, maximum boron diffusion occurred along the grain boundaries of the Alloy 3 sample. For the boron-silicon tests, boron diffused along the grain boundaries of the Alloy 4 sample to a depth of 0.0152 in.—Table 5.

Carbon-chromium Diffusion

In Fig. 10, the diffusion of carbon and chromium into the various high-temperature alloys is shown. The diffusion treatment (4 hr at 1920° F) has produced a darkened band of carbon diffusion below a white, chromium-rich surface layer in the AISI 410 sample. Again, the diffusion of carbon into AISI 347, Alloy 3, Alloy 4 and Alloy 5 has occurred preferentially along the base metal grain boundaries, followed by carbon irrigation from these boundary regions. (Compare Fig. 10 with Fig. 3.) The diffused carbon has reacted with base metal elements to form pale yellow, cubic carbides in the grains of the Alloy 5 sample—Fig. 10E.

The chromium-enriched surface regions of the AISI 410, AISI 347 and Alloy 4 possessed a lower hardness than the base metal regions—Group 9 of Table 4. Both the Alloy 3 and Alloy 5 samples show an increase in surface hardness, after the diffusion treatment. Maximum measurable carbon penetration occurred in the AISI 347 sample—Table 5.

Carbon-iron and Carbon-nickel Diffusion

Diffusion tests with carbon-iron and carbon-nickel produced microstructures which were similar to the reaction structures obtained in Fig. 10 for carbon-chromium diffusion. In these tests, carbon again tended to diffuse intergranularly into the base materials and to react with base metal elements to form carbides. Some incipient volume diffusion by carbon, iron and nickel occurred in the surface grains of the base metals.

Carbon-silicon Diffusion

In Fig. 11, the effects of carbon-silicon diffusion into AISI 347, Alloy 3, Alloy 4 and Alloy 5 are shown. Carbon penetration along grain boundaries and into the grains can be observed in these samples. Incipient volume diffusion by silicon is evident in the surface regions of the base metals. The silicon diffusion has produced a darkened, solid solution band in the Alloy 4 sample (compare Figs. 11C and 7C) and a white, solid solution band in the AISI 347 and Alloy 3 samples—Figs. 11A and 11B. Nickel-silicon rich eutectic structures can be observed on the surfaces of the Alloy 3, Alloy 4 and Alloy 5 samples. Under similar test conditions, a carbon-silicon interaction has apparently retarded the massive carbon migration at 1920° F into the Alloy 5 which occurred in the carbon diffusion sample and carbon-chromium diffusion sample at the same temperature. (Compare Figs. 3E, 10E, and 11D.)

In the carbon-silicon-AISI 410 diffusion sample, no visible carbon diffusion into the AISI 410, martensitic structure could be detected. However, silicon volume diffusion into the AISI 410 produced an iron-silicon rich solid solution at the base metal surface regions, of a nature which was similar to the silicon-rich solid solution at the surface of the AISI 347 sample—Fig. 11A.

Carbon-silicon diffusion has produced an increase in surface hard-

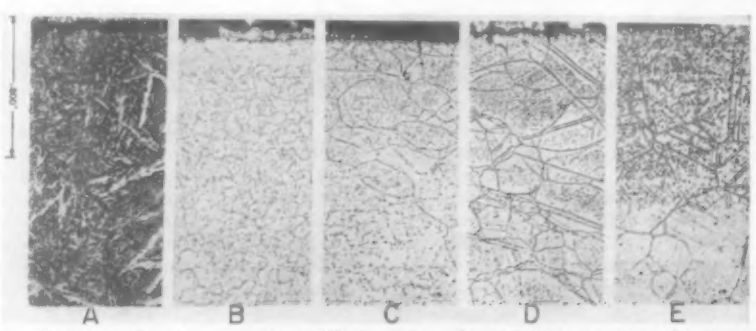

Fig. 10—Effect of carbon-chromium diffusion into various high-temperature alloys; samples were heated for 4 hr at 1920°F: A—AISI 410; B—AISI 347; C—Alloy 3; D—Alloy 4; E—Alloy 5. Fry's etch. × 200 (reduced 50% on reproduction)

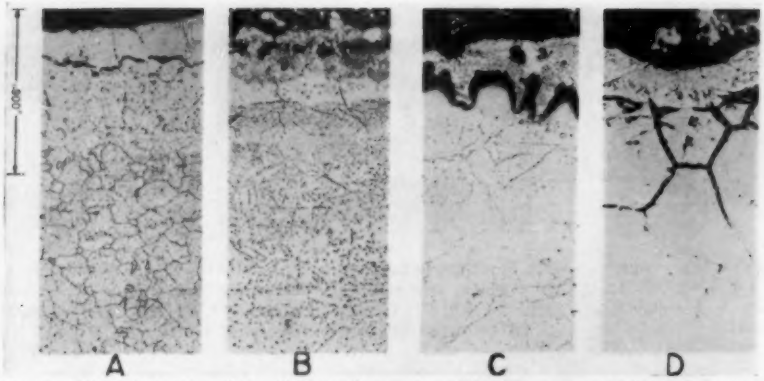

Fig. 11—Effect of carbon-silicon diffusion into various high-temperature alloys; samples were heated for 4 hr at 1920° F: A—AISI 347; B—Alloy 3; C—Alloy 4; D—Alloy 5. Fry's Etch. × 200 (reduced 72% on reproduction)

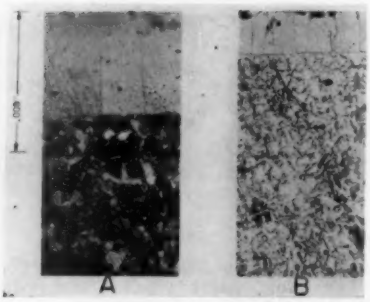

Fig. 12—Effect of iron-silicon diffusion into AISI 410 (left at A) and AISI 347 (right at B) base metals; samples were heated for 24 hr at 1740° F: Fry's Etch. × 200 (reduced 50% on reproduction)

ness of the AISI 347, Alloy 3 and Alloy 4 samples—Group 12 of Table 4. Hardness data on the solid solution and eutectic surface structure are also listed for these samples. Diffusion penetration measurements are listed in Table 5 for the carbon-iron, carbon-nickel and carbon-silicon samples. Considerable diffusion by carbon occurred in all the measurable samples.

Chromium-iron, Chromium-nickel and Chromium-silicon Diffusion

Diffusion tests (24 hr at 1740° F) conducted with chromium-iron, chromium-nickel and chromium-silicon produced similar results. These elements tended to volume diffuse into the base metals and form solid solutions with the base metal elements. In the study of brazing alloy-base metal interface reactions,[1] nickel-chromium-silicon brazing alloys also produced solid solution interface regions when nickel, chromium and silicon diffused into iron-, nickel- or cobalt-base alloys.

Iron-nickel and Iron-silicon Diffusion

Generally, the iron-nickel and iron-silicon diffusion tests again showed that iron, nickel and silicon migrate by a volume diffusion mechanism into the AISI 410, AISI 347, Alloy 3, Alloy 4 and Alloy 5 base metals. An iron-silicon rich, solid solution surface layer, which formed on the AISI 347 sample in Fig. 12A possessed a hardness of 526 KHN while a similar solid solution layer on AISI 410 was 233 KHN—Group 13 of Table 4. The hardness difference in these iron-silicon rich solid solutions may be due to the presence of diffused, base metal elements in these regions. Some indication of slight silicon intergranular diffusion into Alloy 3 and Alloy 4 was observed. Iron-nickel and iron-silicon penetration data have been listed in Table 5. For these samples, a maximum solid solution layer of 0.0072 in. thickness formed by iron-silicon diffusion into the AISI 410 at the 1740° F diffusion temperature.

Nickel-silicon Diffusion

Volume diffusion by nickel and silicon, similar to diffusion by iron and silicon, produced solid solution surface layers on the base materials. Maximum joint-diffusion by nickel and silicon occurred in the AISI 410 sample, where the diffusion treatment of 24 hr at 1740° F produced a nickel-silicon rich solid solution of 0.0092 in. in thickness. Some evidence of slight silicon grain boundary diffusion was observed in the AISI 347 and Alloy 3 base metals.

General Summary on Diffusion Mechanisms

Elements which are present in high-temperature brazing alloys—boron, carbon, chromium, iron, nickel and silicon—and binary combinations of these alloys, have been diffused into various types of high-temperature alloys—AISI 410, AISI 347, Alloy 3, Alloy 4 and Alloy 5. The diffusion mechanisms by which these elements, separately, or in binary combinations, react with the high-temperature alloys have been determined.

The interstitial carbon atom and the relatively-small boron atom rapidly diffuse along the base-metal austenite grain boundaries at elevated temperature. These elements can irrigate from the grain boundaries into the adjoining grains. Incipient volume diffusion by these elements can occur with the elements migrating into the interface grains of the base metal. Wherever these elements diffuse, they can react with base metal elements to form borides or carbides. The grain boundary diffusion, grain irrigation and intermetallic compound formation have been observed in the carbon, boron and carbon-boron diffusion samples prepared in this investigation. Some slight grain boundary diffusion by silicon was evident in a few of the test specimens.

The substitutional atoms—chromium, iron, nickel and silicon—penetrate at a much slower rate, by volume diffusion, into the various base metals. Usually, these elements remain in solution with the base metal elements and form solid solution regions in the diffusion reaction zone. These solid solution reaction structures have been observed in the diffusion specimens prepared in this investigation.

When binary combinations of the diffuser elements are concurrently reacted with the base metals, each diffuser element migrates as previously described. Boron, carbon and, sometimes, silicon rapidly diffuse along grain boundaries and into grains and react with base metal elements to form intermetallic compounds. Chromium, iron, nickel and, usually, silicon slowly migrate by a volume diffusion mechanism into the base metal grains and form solid solutions with the base metal elements. Some deviation in penetration depth measurements, by carbon or boron, occurred in the presence of different substitutional, diffuser elements. This deviation may be due to an interaction between these elements or a reaction between the base metal and diffuser elements, to form carbides or borides on the sample surface. However, these measurements were made on visible diffusion reaction zones, and may differ considerably from

actual depths of penetration values.

Diffusing silicon sometimes combined with nickel, present in Alloy 3, Alloy 4 and Alloy 5, to form a nickel-silicon rich eutectic on the sample surface region. This effect was not noted with other diffuser elements, which would tend to form higher melting temperature eutectics, above the diffusion temperatures which were employed in this investigation.

All the diffusion mechanisms which were observed for the various elements and element combinations are in accordance with the reaction mechanisms which had been derived previously from a comprehensive study of commercial brazing alloy base metal interface reaction structures.[1] In this previous work the base metals were identical to those studied in this investigation.

Conclusions

A microscopic and microhardness examination was made of 105 diffusion samples in which single elements or binary combinations of elements, present in commercial high-temperature brazing alloys, were reacted with AISI 410, AISI 347, Alloy 3, Alloy 4, and Alloy 5 base metals. These tests indicated the following:

1. The interstitial carbon atom, the small boron atom and sometimes the substitutional silicon atom rapidly diffuse along grain boundaries at brazing temperatures of about 1740–2190° F.

(*a*) These elements irrigate into adjoining grain regions.

(*b*) These elements also migrate by incipient volume diffusion into the base metal surface grains.

(*c*) Wherever these elements diffuse, they can, and do, react with base metal elements to form borides, carbides or silicides.

2. Substitutional atoms—chromium, iron, nickel and, generally, silicon—slowly penetrate by volume diffusion into the various base metals.

3. Atoms of the substitutional elements form solid solutions with base metal atoms at the interface diffusion-reaction regions.

4. In binary combination with other elements, each element diffuses according to its individual diffusion mechanism into a particular base metal.

5. The isolated diffusion mechanisms observed for the various elements are in accordance with bonding reaction mechanisms derived from a comprehensive study of commercial brazing alloy reactions with the same high-temperature alloys.

6. Sometimes, diffusing silicon reacts with nickel (in Alloy 3, Alloy 4 and Alloy 5) to form a nickel-silicon rich eutectic at the sample surface region.

Acknowledgment

Thanks are extended to James Nelson, of the Metallographic Laboratory of the Materials Laboratories of Westinghouse Electric Corp., for his work in preparing and photographing the specimens which were used in this work and to F. J. Sabados, of the Metals Processing Lab., who assisted in the preparation of the diffusion samples.

Bibliography

1. Feduska, W., "The Nature of High-temperature Brazing Alloy-base Metal Interface Reactions," THE WELDING JOURNAL, **37** (2), Research Suppl., 62-s to 73-s (1958).

2. Gomberg, H. J., Sinnott, M. J., Upthegrove, C., Flinn, R. H., *et al.*, "High Resolution Autoradiography for Study of Grain Boundaries in Metals," Final Report, Engineering Research Institute, University of Michigan, Project 2029, U. S. Army Ordnance Corps Contract No. DA-20-018-ORD-12150, Project No. TB-121 (DA Project 593-08-023) WAL843/13-19, p. 14 (February 1954).

3. Hansen, M., *Constitution of Binary Alloys*, Second Edition, McGraw-Hill Book Co., Inc., New York, p. 568 (1958).

AN UNUSUAL FRACTURE

(*Continued from page 65-s*)

stress and the prior compression in the region of residual tensile stress which makes cracking possible.

Freudenthal[1] has remarked that cracks sometimes arise spontaneously on the inside bends of concrete reinforcing bars; he has ascribed their origin to the action of internal stresses. Drucker, Mylonas and Lianis[2] have shown that steel specimens taken from material deformed in compression may fracture with little deformation under a subsequent tensile stress. Thus, both the change in the properties of the material brought about by the initial strain and the occurrence of residual stresses on release of the load producing that strain act together to make it possible for cracks to appear on unloading. Mylonas[3] reported the results of tensile tests upon previously deformed notched specimens and explained his results exclusively by the change in the properties of the steel brought about by the prior deformation. In the discussion of the paper, the opposing view was put forward: only residual stresses need be invoked to explain the experimental results. However, it seems that the cracks reported by Mylonas must be similar to those described here, and that an explanation in terms of either factor alone is not satisfactory. For the homogeneously precompressed specimens,[2] the true fracture stress was not much reduced, whereas thumbnail cracks originating from the base of the notch[3] in heterogenously precompressed specimens occurred at very much lower over-all stresses. The difference presumably represents the contribution of the internal stress system and the stress concentration effect of the notch.

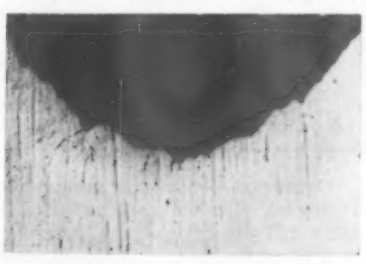

Fig. 2—Compression region of strip specimen before release of load. × 70. (Reduced 50% in reproduction)

Fig. 3—Compression region of strip specimen after release of load. × 70. (Reduced 50% on reproduction)

References

1. Freudenthal, A. M., Discussion of ref. 3, THE WELDING JOURNAL **39** (8), Research Suppl., 365-s (1960).

2. Drucker, D. C., Mylonas, C., and Lianis, G., "Exhaustion of Ductility of E-Steel in Tension Following Compressive Prestrain," *Ibid.*, **39** (3), Research Suppl., 117-s to 120-s (1960).

3. Mylonas, C., "Pressure, Size and Residual Stresses in Static Brittle-Fracture Initiation," *Ibid.*, **38** (10), Research Suppl., 414-s to 424-s (1959).

Properties of Stainless Steel Sandwich Using Low-Density Honeycomb Cores

Tests reveal mechanical properties for PH 15 – 7 Mo stainless steel sandwich structures with various 17 – 7 PH stainless steel honeycomb core densities

BY H. SMALLEN AND W. F. ROBERTS

Introduction

The purpose of this program was to obtain mechanical properties for stainless steel sandwich structures of various honeycomb core densities. The materials of construction were 17 – 7 PH stainless steel core, PH 15 – 7 Mo stainless steel facings and a sterling silver-lithium brazing alloy. Nominal core densities ranged from 2.0 to 7.5 lb per cu ft. The panels were fabricated using furnace brazing techniques and heat treated to the TH 1050 condition. X-ray inspection was used as the acceptance criterion for the brazed panels. Destructive testing included: (1) tension and compression of facing sheets, (2) flatwise tension, flatwise compression and edgewise compression tests of sandwich specimens and (3) determination of the elastic modulus and shear modulus of the core using a Norair-developed dynamic testing technique.

There are numerous combinations of variables (material, foil thickness, face thickness, etc.) that can be used for honeycomb sandwich structures. A very extensive program would be necessary to perform all of the desired tests on these many sandwich configurations. This program was aimed at obtaining information for a typical construction, and ranging down to a very low-density core. This was done to establish an indication of the limitations and potentials of the low-density range from fabrication and design standpoints. The material and thickness of the facing can be selected more readily than the core owing to the nonhomogeneity and greater combinations of variables to be considered for the core. However, since the core is used to support the faces in addition to carrying shear, it does affect the load-carrying ability of the faces. The magnitude of this effect is important in determining the feasibility of low-density cores.

The eight different panel configurations used in this program are shown in Table 1. These configurations represent various combinations of three cell sizes (1/4, 3/8 and 1/2 in.), three foil thicknesses (0.001, 0.0015 and 0.002 in.), and two face thicknesses (0.020 and 0.032 in.). The core density range is from 7.5 to 2.0 lb/cu ft. The core thickness for all panels was 0.50 in.

Table 1—Summary of Panel Parameters

Panel designation	Cell size, in.	Face thickness, in.	Foil thickness, in.	Measured density lb per cu ft
A	1/4	0.02	0.002	7.74
B	1/4	0.032	0.002	7.74
C	3/8	0.02	0.002	5.08
D	3/8	0.032	0.002	5.08
E	1/2	0.02	0.002	3.76
F	1/2	0.032	0.002	3.76
G	1/2	0.032	0.0015	2.86
H	1/2	0.032	0.001	2.06

Qualification of Core

Core qualification tests were made in accordance with Reference 1. Tests performed were: (1) density, (2) flatwise compression, (3) core delamination and (4) node weld shear. Average results are tabulated below:

Core Qualification Test Results

Cell size, in.	Foil thickness, mil	Density, lb per cu ft	Flatwise compression, psi	Core delamination, psi	Node weld shear, lb/in. of weld
1/4	2	7.74	411	106	122
3/8	2	5.08	207	72	125
1/2	2	3.76	118	54	126
1/2	1 1/2	2.86	68.5	44	103
1/2	1	2.06	28.2	33	23

Test Procedures and Results

The destructive testing techniques were given careful consideration in order to obtain the most accurate and consistent strength values possible from the relatively limited number of tests performed. In general three specimens were tested for each type of static test and each panel configuration. Two specimens for each panel configuration were tested for the modulus of elasticity and four specimens (two sets) for the shear modulus. Static testing of the flatwise tension, flatwise compression and edgewise compression specimens was accomplished by the procedures outlined in Reference 1, with certain modifications.

Detail test concerning procedures follow together with results for each type of test performed. A discussion of the results concludes each individual section, and a general discussion of the over-all results is contained in the conclusions.

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., Apr. 25–29, 1960.

Table 2—Summary of Average Face Coupon Test Results

Panel No.	Ftu, psi	Fty, psi	Fcy, psi	Elongation in 2 in., %
1A	205,200	194,800	...	5.6
2A	203,000	196,100	...	6.2
1B	205,500	196,300	...	6.0
2B	200,000	194,300	...	6.0
5B	214,200	207,000	...	6.2
1C	217,300	207,900	...	5.0
2C	218,400	210,800	...	5.8
4C	211,800	205,000	...	5.3
3D	216,900	209,000	215,200	5.3
6D	205,700	192,400	209,700	5.5
1E	206,100	197,500	207,800	4.3[a]
3E	203,600	188,700	215,400	5.7
1F	191,900	166,700[a]	179,700	11.8
3F	192,900	169,100[a]	181,700	11.3
3G	212,500	205,100	210,600	5.0
5G	211,500	204,100	218,000	5.5
6G	211,200	204,700	217,500	5.5
1H	213,100	206,000	217,200	5.2
2H	209,900	202,500	221,900	6.5
3H	209,500	201,900	218,400	6.5
4H	213,200	206,800	218,000	6.5
Min	190,000	170,000	...	5.0

Vendor properties

	Ftu, psi	Fty, psi	Fcy, psi	Elongation in 2 in., %
Minimum	190,000	170,000	...	5
Typical	210,000	200,000	217,000	7

[a] Values below vendor minimum.

Tension and Compression

Face Tension and Compression

Coupon preparation and testing of face tension and compression specimens were done in accordance with Reference 2. The average results for each panel used in the tests are shown in Table 2.

Flatwise Tension

This test was performed primarily to determine the strength of the brazed joint and/or honeycomb core. A refinement in specimen preparation was to machine the specimen so that all exposed edges had unbroken cells. Typical specimen dimensions for the various cell sizes were as follows:

Cell size, in.	Dimension, sq. in.
1/4	2.00
3/8	2.55
1/2	3.45

The specimens were bonded to the test blocks using FM-47 adhesive. Standard pin-supported blocks were used to minimize eccentric loading.

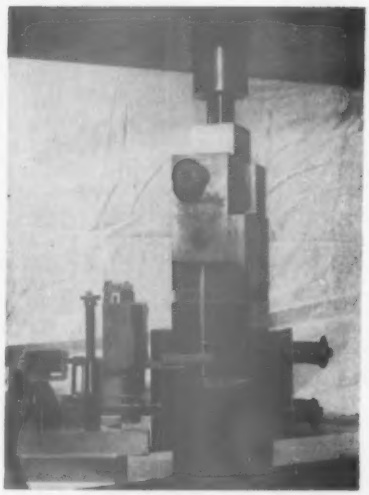

Fig. 1—Flatwise tension test setup

The load was applied at a constant rate of movement such that the maximum load occurred in most cases between 3 and 6 min. A Baldwin PD1M compressometer was used to provide a load-deformation curve up to the failing load. The test setup is shown in Fig. 1. Average flatwise tension results are tabulated in Table 3, while Fig. 2 presents the flatwise tension stress plotted against core density.

All of the specimens with a nominal core density of 7.5 lb per cu ft experienced a braze failure, while the others (with one exception) had core or core/braze failures. This indicates that for flatwise tension, the brazed joint is critical for densities of 7.5 lb per cu ft and greater. However, this is not conclusive, since the variation in cell size and foil thickness of the core must also be taken into consideration.

Table 3—Average Flatwise Tension, Flatwise Compression and Edgewise Compression Results

Panel	Flatwise tension strength F_{tu}, psi	K_1	F_F, psi	Type of failure	Flatwise compression strength F_{cu}, psi	K_1	F_F, psi	Edgewise compression strength Fc, psi	Type of failure
A	2148	62.5	134,300	I	1121	62.5	70,100	214,100	I_A, III_A
B	2289	62.5	143,100	I	1152	62.5	72,000	222,300	I, II_A
C	1632	62.5	149,100	II	638	95.2	60,800	173,100	I, I_A, II_A
D	1739	95.2	165,600	I, II, III	657	95.2	62,500	142,900	II
E	1376	128.7	177,100	II, III	360	128.7	46,300	118,300	I, II
F	1131	128.7	145,500	II, III	333	128.7	42,900	113,600	I
G	887	169.2	150,100	II, III	300	169.2	50,800	101,700	I
H	369	234.9	86,700	II	194	234.9	45,700	59,100	I

$K_1 = \frac{\text{Density of solid steel}}{\text{Measured foil density}}$

Flatwise tension type of failure
I—Brazed joint, upper face
II—Core
III—Core and brazed joint

Flatwise compression type of failure
Compression failures were core buckling on four sides (symmetrical), except in three cases.

Edgewise compression type of failure
I—Face buckling near center
II—Face buckling near lower end
III—Face buckling near end and secondary end failure

Subscript A indicates use of aluminum bearing plates. All others used clamping fixture.

The test values for panel F were low as shown in Fig. 2. This is probably due to the inadvertent overaging of panels 1F and 3F from which these specimens were taken. The curve in Fig. 2 shows a decreasing slope as the core density increases, which indicates that the flatwise tensile stress can be raised very rapidly at the low-density range by an increase in core density and less rapidly at the higher density range.

Flatwise Compression

The specimens were machined so that all exposed edges had unbroken cells, as in the case of the flatwise tension specimens. Nominal dimensions for the specimens and the matching compression blocks were as follows:

Cell size, in.	Dimensions, sq. in.
1/4	2.90
3/8	3.10
1/2	4.10

Specimen dimensions were chosen to give at least 64 completely enclosed cells as specified in Reference 1. Specimens were bonded to 3-in. thick blocks with Eastman 910 adhesive. Thick blocks were used to allow regrinding and reuse of the blocks, since a 2-in. thick block was considered the minimum to assure uniform load distribution on the specimen.

Flatwise compression loads were applied using one fixed and one self-adjusting loading head. As in the flatwise tensile tests, load was applied at a constant rate of movement such that the maximum load occurred in most cases between 3 and 6 min. Figure 3 shows the test setup with the Baldwin PD1M compressometer to provide a load-deformation curve to the failing load.

Fig. 3—Flatwise compression test setup

The average flatwise compression test results for each panel tested are tabulated in Table 3; the flatwise compressive stress plotted against core density is shown in Fig. 4.

The flatwise compression tests give an indication of the stability of the core, and all of the failures are a result of core buckling. The core buckling will be a function of the panel thickness, which means that these test results are actually valid only for the 0.50-in. thick panels used in all of these tests. The results shown in Fig. 4 indicate a linear variation of flatwise compressive stress with core density over the density range of 3 to 8 lb per cu ft.

Edgewise Compression

Several refinements were made to the edgewise compression test procedures specified in Reference 1. Unbroken core cells were maintained on the specimen sides to avoid edge effects which could cause premature buckling. The loaded ends of the specimens were filled with an epoxy and carefully machined back to allow loading of the face sheets without causing a local end failure. These two refinements were considered to be especially important for the low-density-core specimens.

All of the specimens were 4 in. long, but the widths varied slightly as required to maintain unbroken cells on the edges. The nominal specimen dimensions for the various cell sizes were as follows:

Cell size, in.	Specimen dimensions, in.
1/4	2.70 × 4.00
3/8	2.75 × 4.00
1/2	3.10 × 4.00

The ends were machined flat, free of burrs, parallel to each other and perpendicular to the length of the specimen. The exposed cores at the two ends of the specimen were filled with Kish 422 epoxy potting compound and machined down 0.020 ±0.005 in. from the ends.

The first edgewise compression specimens were tested by applying the load with fixed parallel heads, using bearing plates between the specimen and the test heads. The bearing plates were made from 7075-T6 aluminum plate to allow the specimen face sheets to dig into them and prevent lateral buckling. This method gave apparently satisfactory strength values, but some secondary end failures were caused when the specimen slipped or cut through the plate. Therefore, a clamping fix-

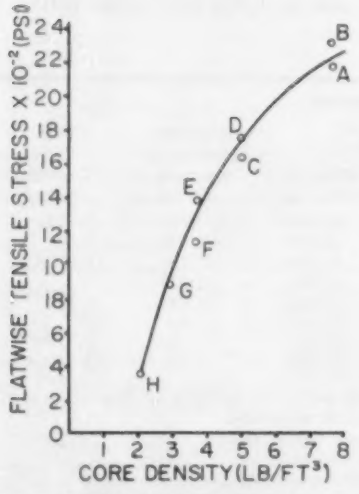

Fig. 2—Flatwise tensile stress vs. core density (panels A, B, C, D, E, F, G and H)

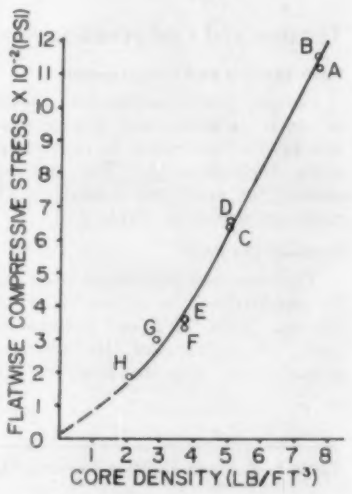

Fig. 4—Flatwise compressive stress vs. core density (pane s A, B, C, D, E, F, G and H)

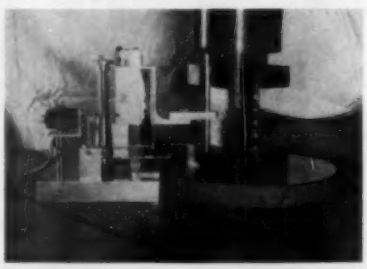

Fig. 5—Edgewise compression test setup

ture similar to that specified in Reference 1 was tried and found to be very satisfactory. The final test setup, used for the majority of the tests, is shown in Fig. 5.

A PD1M compressometer was used to provide a load-deflection curve. The load was applied at a constant rate of head movement which was such that the maximum load occurred between 3 and 6 min in most cases. However, for the larger cell sizes most of the failures occurred between 2 and 3 min.

The average results of the edgewise compression tests are tabulated in Table 3. The failures for panels E through H are shown in Fig. 6. Figure 7 shows the edgewise compressive stress plotted against core density, and Fig. 8 the ratio of edgewise compressive stress to Ftu of the face material, plotted against core density. The edgewise compressive stress is plotted against both flatwise tensile stress and flatwise compressive stress in Fig. 9, and the strength/weight ratio vs. core density is shown in Fig. 10.

The results for panel D are obviously low as shown in Figs. 7 through 10. Inspection of these three specimens after test showed strong evidence of eccentric loading during testing. The specimen ends were offset in contrast to all other tests which exhibited evidence of uniform loading. For this reason this point is not used in plotting the various curves. With this point eliminated, the edgewise compression test results are very uniform, especially considering the relatively

Fig. 6—Edgewise compression specimens (panels E, F, G and H)

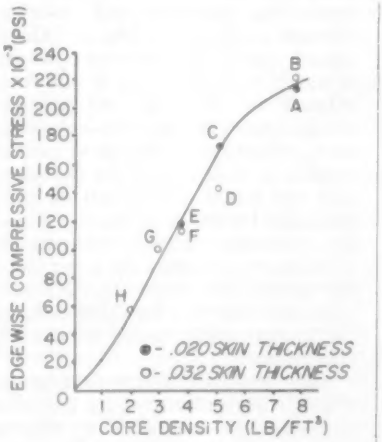

Fig. 7—Edgewise compressive stress vs. core density (panels A, B, C, D, E, F, G and H)

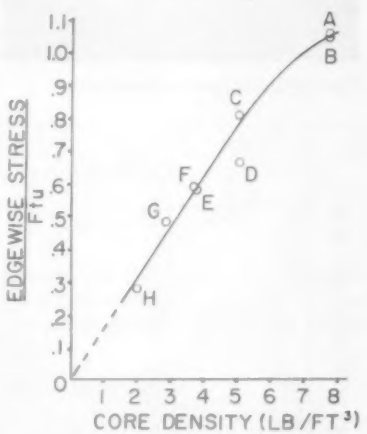

Fig. 8—Edgewise stress/Ftu vs. core density (panels A, B, C, D, E, F, G and H)

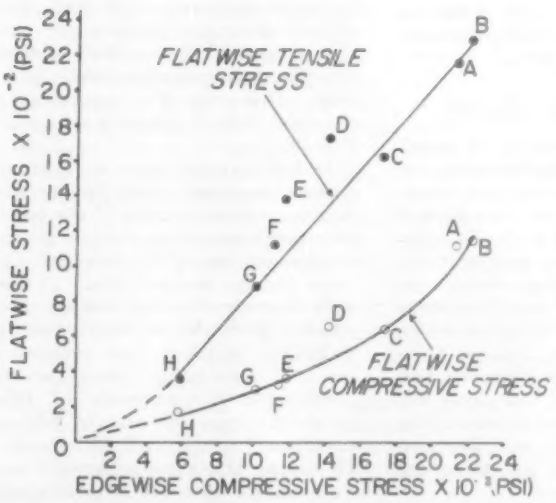

Fig. 9—Edgewise compressive stress vs. flatwise stress (panels A, B, C, D, E, F, G and H)

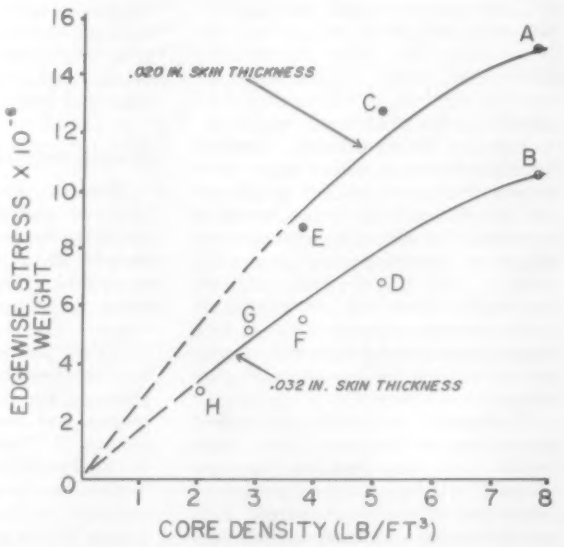

Fig. 10—Strength/weight ratio vs. core density (panels A, B, C, D, E, F, G and H)

Fig. 11—Modulus of elasticity test setup

Fig. 12—Shear modulus test setup

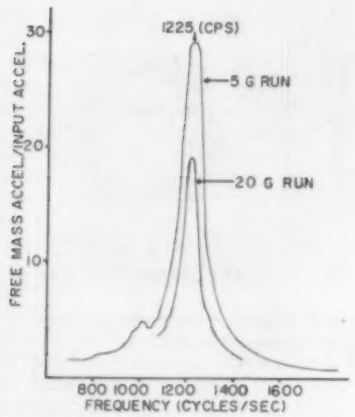

Fig. 13—Typical recording dynamic modulus test (modulus of elasticity test—specimen 1AY2)

small number of tests conducted.

Figure 7 shows a linear variation in edgewise compressive stress over a core density range of 2 to 5 lb per cu ft. From 5 to 8 lb per cu ft density, the edgewise compressive stress is increasing at a decreasing rate. The 0.020- and 0.032-in. thickness faces are on the same curve, even though the 0.020-in. face might normally be expected to give lower stresses for a particular core density.

Evidently this thickness effect occurs at a thickness lower than 0.020 in. An increase in core density allows a greater portion of the face strength to be utilized. This ratio is shown plotted against core density in Fig. 8 and is seen to exceed 1.0 for the highest core density. The ratios were obtained by dividing the edgewise compressive stress by the average face coupon test results. Ftu was used since Fcy was not obtained for panels A through C. This curve naturally resembles Fig. 7 very closely.

The flatwise tension, flatwise compression and edgewise compression test results should actually be closely related. Basically, the flatwise tensile and compressive stresses are not design values, since a sandwich structure would seldom be highly loaded in this way. However, the sandwich core will be indirectly loaded in this manner in carrying out its basic function of supporting the skins when they are loaded in compression. The relationship between the edgewise and flatwise stresses is shown in Fig. 9. Once again, panel D edgewise stress is shown to be low and is not considered in drawing the curves. When loaded in edgewise compression, wrinkling of the faces causes tension or compression on the core, and the initial failure can be precipitated by either of these. Since the allowable flatwise compressive stresses are considerably lower than the flatwise tensile stresses, it seems probable that the buckling failures for these panels began from core compression.

The strength/weight ratios in Fig. 10 were obtained by dividing the edgewise compressive stresses by the panel weights. The test points are meager and scattered, but the curves appear to be reasonable approximations. These curves show that the strength/weight ratio is constantly increasing with an increase in the core density, and the maximum ratio is at a higher density than 8 lb per cu ft. It is also shown that the 0.020-in. face thickness gives a higher strength/weight ratio than the 0.032- in. faces.

Dynamic Determination of Moduli

Efforts to obtain consistent values of shear modulus and modulus of elasticity for honeycomb core materials by static methods were not too successful. This led to the development of a dynamic testing technique. The preliminary results using this technique were excellent and are described in a report which presents the theory, testing techniques and some preliminary test results.[3] Therefore, this paper will not deal with the development of this method but primarily with the presentation of the test results on the panels in this program.

The dimensions of the test specimen were chosen to give unbroken cells on all four sides. Nominal specimen dimensions were as follows:

Cell size, in.	Type of panel	Specimen size, in.
1/4	A, B	3.60 × 3.60
3/8	C, D	3.60 × 3.70
1/2	E, F, G, H	3.80 × 3.90

The larger dimensions were parallel to the ribbon direction. A photograph of the modulus of elasticity test setup is shown in Fig. 11; a photograph of the shear modulus test setup is shown in Fig. 12.

The same test procedure was used for both the modulus of elasticity and shear modulus tests. The specimen was mounted on an M.B. C-25HB shaker table. The input acceleration and free mass acceleration were then each measured by a pair of accelerometers, and a transmissibility plotter was used to directly plot the frequency vs. the ratio of the average free mass acceleration to the average input acceleration. (This plot should show a single distinct peak at the resonant frequency.) A preliminary resonant frequency search was made from 100 to 2000 cps while maintaining the acceleration of the free mass at ±5 g's. Following this, a final resonant frequency search was made with a ±10–20 g acceleration of the free mass and over a frequency range of not more than 200 cps. This final search was accomplished in the minimum number of cycles to prevent fatigue damage to the specimen. The resonant frequency (peak) was accurately located by using the digital counter on the input equipment. The shear modulus test was conducted twice for each specimen—first with the ribbon direction parallel to the shaker axis and then with the ribbon direction perpendicular to the shaker axis. The copy of a typical plot obtained from the tests is shown in Fig. 13.

Unfortunately, there were numerous unsuccessful tests for various reasons such as failures of the bond between the specimen and test block, instrumentation difficulties and fatigue damage to specimens. It was also discovered as the testing progressed that the dynamic testing technique is much less successful on the low-density cores, which constituted the majority of this program, than on core of higher densities (7.5 lb per cu ft and above). Of course, this same statement can be made for all types of tests, since the low-density cores are inherently more difficult to test.

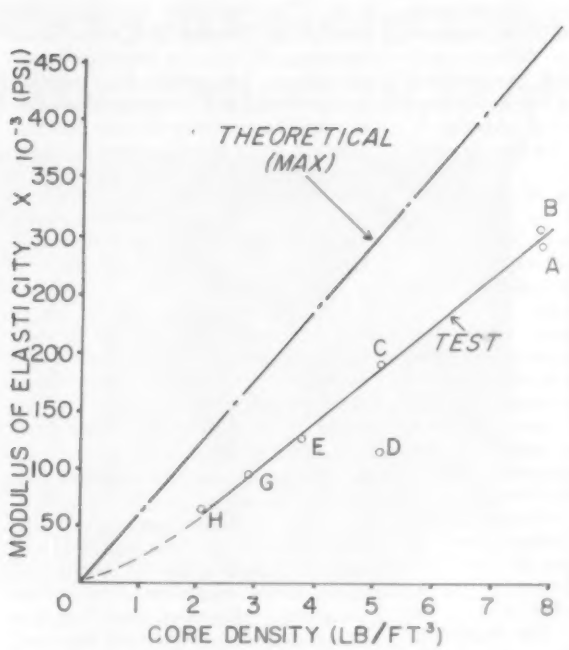

Fig. 14—Modulus of elasticity vs. core density (panels A, B, C, D, E, G and H)

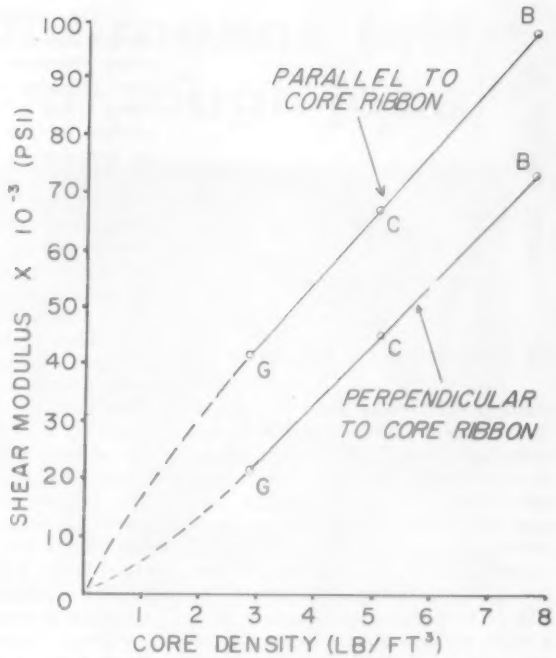

Fig. 15—Shear modulus vs. core density (panels B, C and G)

Modulus Test Results

Modulus of Elasticity

The modulus of elasticity and shear modulus test values are tabulated in Table 4. The modulus of elasticity test results were very consistent, with the exception of panel D. There were a number of factors which could cause this but, based on experience gained during the testing, the most logical explanation is that the bond between the specimen and test blocks was too thick and/or was not uniform over the specimen area. Both of these factors can easily contribute to an indication of a lower modulus. It will be noted that this is the same type of panel (panel D) that gave low strength values in the edgewise compression tests. However, it is felt that there is no connection between these results for three reasons: (1) the edgewise compression specimens and the modulus specimens were taken from different panels, (2) all of the type D panels showed good strength values in all of the other tests, and (3) the cause of the low edgewise compression test results has been previously proved and this same reason would not account for the low modulus of elasticity values.

Figure 14 shows a linear variation of modulus of elasticity over the core density range tested. This is as it should be, since the theoretical variation is also linear. The test values are naturally lower than the theoretical since the theoretical represents the maximum obtainable values by a direct ratio of the core density to a solid material. When dealing with a nonhomogeneous material such as honeycomb and considering all of the variables which affect the panel strength, it can be realized that the theoretical maximum can never be attained. The slope $(E/\rho c)$ of the theoretical line is 59,900 while the test slope is 43,600. It is also interesting to note that the test values vary from 43% of the theoretical at a density of 2 lb per cu ft to 65% at 8 lb per cu ft. This points out the greater reliability of this test and the inherently smaller variation in modulus at the higher density.

Shear Modulus

The shear test results are admittedly meager. However, they are consistent as shown in Fig. 15. The shear modulus is seen to vary linearly with core density over the 3 to 8 lb per cu ft range tested. The modulus parallel to the core is shown to be greater than that perpendicular to the core, as expected. The two slopes are nearly the same: 11,500 parallel to the ribbon and 10,600 perpendicular. There are definite indications that these tests are more accurate for the higher density cores. The reasons for this are the same as discussed for the modulus of elasticity tests. This is best pointed out by noting the shape factor (K_2) values for the three specimens. These values are shown in relation to core density in Fig. 16.

This factor is intended to correct for the edge conditions of the specimen, since the basic shear modulus calculations are based on the assumption of uniform stress. As explained in Reference 3, the shape factors, relating maximum and average stresses, will be greater than 1.0 (uniform shear) and probably less than 1.5 (parabolic shear for elementary beam theory). The values obtained in these tests exceeded this range and must consequently be assumed to in-

Table 4—Test Results: Shear Modulus and Modulus of Elasticity

Panel	Modulus of elasticity—E test, psi	Modulus of elasticity—E theo, psi	Shear modulus G long, psi	G transverse, psi
A	293,800	463,600	...	...
B	308,000	463,600	98,900	73,400
C	191,800	304,300	67,300	45,800
D	110,400	304,300	...	...
E	125,100	225,200	...	...
G	90,600	171,300	42,200	21,700
H	64,100	123,400	...	...

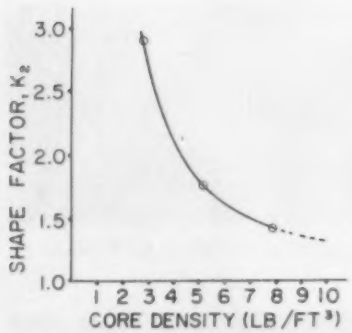

Fig. 16—Shape factor vs. core density

clude other factors than the shape factor alone. Since this factor increases too steadily at lower densities it is concluded that the decreasing core density—i.e., increasing cell size and decreasing foil thickness—introduced additional conditions to cause a higher apparent shape factor. Extrapolating the curve in Fig. 16 to higher densities show that a more realistic shape factor can be expected at higher densities than those used in these tests.

Conclusions

In addition to obtaining some design information on stainless steel honeycomb, this program resulted in the acquiring of knowledge and experience in the fabrication and testing of this type of structure. Consequently, some general conclusions can be made in each of these fields:

1. The fabrication, testing and design use of stainless steel honeycomb becomes more difficult and less reliable for the low-density cores. All of the work accomplished in this program appears to be unfavorable for the low-density cores.

2. Various degrees of core wrinkling were obtained for all of the panels except those with a core density of 7.74 lb per cu ft. This prewrinkling had an indeterminate effect on the test results.

3. The honeycomb specimen strength decreases linearly for most tests, with a decrease in core density. This decrease in strength is not offset by the weight decrease, since the strength/weight ratio also decreased with decreasing core density. The highest strength/weight ratio would be obtained at higher densities than the maximum used in these tests (7.74 lb per cu ft). The 0.020-in skins gave a higher strength/weight ratio than the 0.032-in. skins. Consequently, these tests make the thinner skin and higher density core appear more promising.

4. The testing of stainless steel honeycomb specimens is difficult. Some of the difficulties can be overcome by exercising care in the preparation of the specimens and testing, but the development of new techniques is also required. One particular need is for a good method for obtaining core shear allowables.

5. The dynamic modulus test results are limited but show good promise, not only for modulus determinations but also for possible applications in nondestructive testing and honeycomb fatigue testing. Current work is being done on these two applications as a direct outgrowth of the work in this program. The edgewise compressive stresses are the most useful design information obtained. Flatwise tension is a good indication of the brazed joint/core strength, but is not of much design use. Both flatwise tension and flatwise compression can be related to edgewise compression, since an edgewise failure is precipitated in one of these manners.

6. There are many more combinations of panel parameters that should be investigated. Based on the work in this program, the higher density range—7.5 lb per cu ft and higher—appears more promising. All of these tests were at room temperature. However, since this type of structure is to be used in elevated-temperature applications, there is a need for elevated-temperature design information. These needs are a logical continuation of this work.

References

1. "Test Procedures for High Temperature Sandwich Structure," Aerospace Industries Association ATC Report No. ARTC-17 (June 15, 1958).

2. ASTM Standards E8-57T and E9-52T.

3. "Dynamic Testing for Elastic Moduli of Honeycomb Cores," Norair Report No. NOR-59-384 by A. S. Benson (July 1959).

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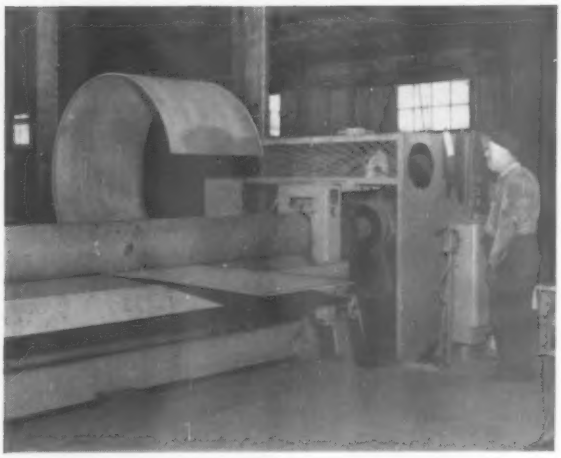

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